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PHYSICAL GEOGRAPHY AND MILITARY ENVIRONMENT IN A TRANSECT OF THE UTAH AND COLORADO ROCKIES

Will F. Thompson

Together with bibliography and climatic maps from the final report of Contract DA19-129-AMC-472(N), August 1966:

"Route 40 Mountain Environment Transect, Colorado and Utah," by John James, with contributions by Everett Peterson and others, edited by John Marr, submitted by the Institute of Arctic and Alpine Research, University of Colorado.

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FOREWORD

In 1964 a contract was let by the U. S. Army to the Institute for Arctic and Alpine Research of the University of Colorado (Boulder) to study the physical geography of a mountainous strip of terrain in Colorado and Utah. The strip (study transect) is 370 miles from west to east and 70 miles wide, and is quite representative of the southern and central Rocky Mountains. The final report of that contract, submitted in 1966, is an accurate and comprehensive analysis of the transect, but it was too bulky for wide distribution in the Army. Furthermore, the investigators made no attempt to interpret their findings for military application.

This version of the study makes that interpretation. As it points out, military application of information about a study area in which actual warfare is improbable must be based on the concept of environmental analogy. That is, the regional environmental system characteristic of the North American terrain described here, which has an only moderately moist continental mountain climate, is known to have much in common with similar climate/terrain systems in certain Eurasian interior regions. Localities and regions on the two continents do not duplicate one another precisely, so that environmental analogy is always a relative matter. Everything else being the same, however, a person familiar with the terrain described here will have much less difficulty than one who is not in solving terrain-related tactical problems in environmentally analogous Eurasian regions.

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ABSTRACT

The crests and slopes of mountain ranges, and basin floors intervening between them, along U. S. Route 40 between Salt Lake City and the Denver-Boulder area, are described here by means of text, 70 photographs, and 8 maps with climatic and topographic data. The bibliography contains 570 entries. All of the highly varied terrain of the study transect is found to be accessible to military forces, and it could all be involved to one degree or another in any warfare which might occur there. Actual warfare in the study transect is not envisioned, but combat in analogous Eurasian terrain is a possibility which cannot be discounted for various reasons.

Particular features of the terrain are examined and discussed here with respect to the nature and extent of their characteristic environmental rigors, their trafficability, the prevalence of defile problems, and the potential usefulness of aerial mobility. It is concluded that small irregular forces are at great advantage in high mountain terrain as compared with large regular formations, and that the military advantages of advanced technology have until now been minimal there, but that aerial mobility, which bypasses defiles, will alter that situation in the near future.

PHYSICAL GEOGRAPHY AND MILITARY ENVIRONMENT IN A TRANSECT OF THE UTAH AND COLORADO ROCKIES

I. The Scope and Purpose of the Report

This study describes for military readers a strip of mountains and plateaus in the Rocky Mountains in which warfare is not foreseen. However, the terrain of the study transect is considered similar to that of broad regions in mid-Asia which may be of increasing military significance. A useful degree of climatic, vegetative, and topographic analogy exists between that part of the Rockies and parts of interior Turkey, northern Iran, northern Afghanistan, northern Pakistan, Turkestan, the Altai region, northern Mongolia, and eastern Tibet, wherever semiarid, forested, and alpine vegetation zones are all present and local relief does not much exceed 6,000 or 7,000 feet. Even among the big mountains which exist in some of those regions, particular altitudinal vegetation zones and their associated slopes are believed to be quite like corresponding zones discussed here.

The Asian regions listed above contain diverse terrain. So does that which is discussed and illustrated here. However, nothing described in this study is analogous to the severe environment of high Tibet, to the central deserts of Sinkiang and Mongolia, or to the great, treeless, desert ranges which separate Tibet from Sinkiang and enclose the Tarim depression. The most extreme environments of central Asia are more severe than anything in North America.

The parts of Asia which are cited here as being analogous in some degree to the study transect have all for a number of centuries been remote from any warfare which was either on a large scale or which disturbed the western world. However, the central location of those regions made them very important in earlier times, and the airmobile concept, together with the continuing advance of aeronautical technology, may soon make them critical again. While reading this report it might be well to consider what response could be made to a strong airborne attack on any of several lightly populated, mountainous plateau regions along the axial frontier of Eurasia, and what the consequences might be to United States policy if they could not be successfully defended.

This study is derived from the final report of Contract No. DA19-129-AMC-472(N), submitted to this office by the Institute for Arctic and Alpine Research of the University of Colorado on 31 August 1966. That report was written by John W. James with extensive contributions by Everett Peterson, and was edited by John W. Marr, director of the Institute.

The present version is greatly reduced in length and has been entirely rewritten and newly illustrated, except where credit is specifically given to the prior report. Objectives of the rewrite have been readability and the introduction of discussion and concepts linking physical geographic findings to military application. The Institute report was particularly strong in the climatic and vegetation fields, which have been greatly condensed here.

The format of the present report has been developed from that of the illustrated section of the Institute study, which was very well done but was in color and stressed plant ecology. Black and white has been used here for convenience in publication, and the emphasis is military.

Beginning with section III, each section of this report deals with a subregion of the study transect. Each refers to several photographs, and usually ends with a short military summary, as does the report itself. Figures 1 through 70 are photographs of landscapes referred to in the text. Figures 71 to 78 are maps which should be carefully studied and also referred to while reading the text.

Figure 71 shows topography and the location of principal features in the study transect. Figure 72 shows the locations of Figures 3 through 70, which are views within the study transect. Figures 73 through 77 are climatic maps prepared by John James for the contract report. Figure 78 shows local relief, which is a very important factor in the physical geography of the study transect. However, its presentation in the form of a map involves a new technique with which readers are not familiar. Careful attention to both the map and the legend is requested.

II. The Continental Position and Climatic Character of the Study Transect

The study transect described here is about 70 miles wide from north to south, is about 370 miles long from west to east, and is 600 miles from the Pacific at its western end. It extends across the grain of the central and southern Rockies and is quite representative of that region. The western half of the transect is a zone beginning at Salt Lake City, Utah, where it lies between the 40th and 41st parallels. Its eastern half is offset a few miles southward and then trends slightly south of east to Denver and Boulder in Colorado. (See maps, Figs. 71 to 78.)

Distance from the sea, and particularly the Sierra-Cascade mountain barrier between it and the sea (Fig. 1), affect the climate of the transect, and therefore its topographic and biological character. The coastal mountain barrier is important because it limits the flow of airborne moisture to the Rockies from the Pacific, from which most of their precipitation comes. In this report the words "windward" and "lee" are used with reference to the Pacific westerlies. The windward (west) side of a mid-latitude range is generally fairly moist. Its east side is usually relatively dry and is termed its lee.

There is also a spring and summer counterflow of moisture into the southern and central Rockies from the Gulf of Mexico which is reminiscent of the Asiatic monsoon, though much less massive and regular. Occurrence of the two kinds of moisture in that mountain region produces precipitation regimes, and precipitation distributions relative to relief, which are similar to those in the westernmost reaches of monsoon influence in northern Pakistan and Afghanistan. Pacific moisture falls in the southern and central Rockies primarily during the six winter months (November to April). Summer precipitation is largely Gulf moisture, plus moisture evaporated from the land and re-precipitated. Much of it falls as summer thunderstorms which would be dangerous to troops stationed on high range crests.

The relative importance of the two major precipitation sources can be followed climatologically across the study transect by noting the relative strength of local precipitation maxima in winter and summer. From the Uinta area eastward, low-level stations and those in particularly sheltered valley and basin sites even at moderately high levels generally have summer, spring, or autumn maxima of precipitation. In that part of the transect the prevalence and strength of winter maxima (precipitation derived from the Pacific) are related to annual precipitation amount, and therefore generally increase with altitude, whereas such maxima are usual at all altitudes both in the Wasatch and in the valleys and hills between that range and the Uintas.

Looking more closely at the climatic pattern in order to understand its detailed relationship to topography, it is seen that the most fundamental geographical control is the inverse relationship which is described

below between temperature and altitude. Its effects are strongly reinforced by those of a less rigorous but nevertheless strong positive correlation between precipitation and altitude.

To those two correlations between climate and altitude we probably should add a third for the levels we are concerned with in the study transect. It is due to an inverse relationship between thermal radiation and cloud cover. However, cloud cover, like precipitation, is correlated only in broad terms with altitude, since both diminish in the lee of ranges and do not always rise to their highest crests. Furthermore, summits get strong radiation in clear weather.

Those considerations tend to offset, but do not cancel out, the fact that within the limits of altitude which most concern us here, cloud cover increases over mountain ranges, particularly over the western slopes of those which are transverse to the westerly winds, and that the clouds reduce the mean flux of thermal radiation there. On the whole, cloud cover is light in the study transect, so that its temperature and radiation regimes show strong contrast between day and night and between summer and winter. With respect to air temperature, station data indicate that such contrast diminishes with altitude.

Data are insufficient to support a similar statement about the radiation flux, but on the whole it also probably diminishes upward within the altitude range which concerns us here. In that respect, as in various others, the Rockies seem to differ from the Alps, which have persistent lowland cloud in winter and therefore have a relatively stronger radiation flux on their uplands, particularly in lee regions.

Generally speaking, summer temperatures in the study transect decrease 3.3 Fahrenheit degrees per 1,000 feet of elevation. At 5,000 feet, which is low in the transect, July mean temperatures are between 66°F and 77°F at various stations. At 8,500 feet they are between 55° and 65°. Upward extrapolation of that rate in the transect agrees reasonably well on the whole with the widely accepted rule of thumb that thermal timberlines approximate the 50°F mean July isotherm. However, the 10,000-foot timberline of the Wasatch above Salt Lake City is apparently depressed below that level by heavy snow.

A similar altitudinal thermal gradient would exist in the transect in winter, with January temperatures at any given level roughly 40 Fahrenheit degrees lower than in July, except that strong thermal inversions occur in all of its basins at that season, even at relatively low levels. Under the clear skies of the Uinta basin the difference in mean temperature between July and January is therefore consistently greater than 50 Fahrenheit degrees and approaches 60 Fahrenheit degrees near and below the 5,000-foot level. The lowest stations in the Basin average 15°F or less in

January, as compared with 25°F or more at that level near Salt Lake City. At 11,000-foot timberlines in the transect, January mean temperatures are believed to be very little colder.

Most other climatic stations in the study transect also have basin sites, but they are either cloudier or better ventilated in winter than the Uinta Basin. Their annual ranges of mean monthly temperatures nearly all lie between 40 and 50 Fahrenheit degrees.

To put our discussion of the study transect in a broader geographic context, let us consider Figures 1 and 2 which show ranges between it and the Pacific. The Cascades (Fig. 1) get heavy precipitation, whereas precipitation in the Ruby Range (Fig. 2) is no more than in some Rocky Mountain ranges.

Figure 1. The Cascades, together with the northern Sierras, are the principal topographic barrier sheltering the central and southern Rockies from cloud cover and precipitation. This view of Snowfield Peak in the Cascades in July 1968 will permit comparison of their landscape with that of the Rockies.

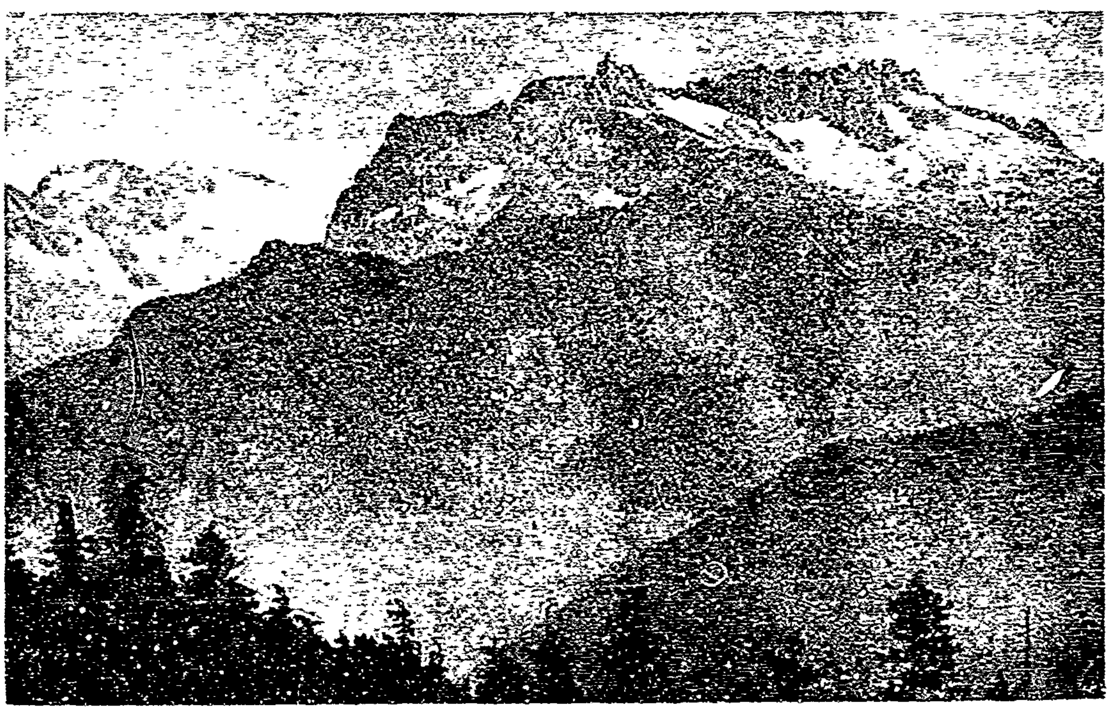


Figure 1. The Cascades

Snowfield Peak is 8,350 feet high, with a 6,000-foot timberline. Many non-volcanic peaks in the Cascades stand higher above the tree line but only one exceeds it by 3,000 feet. The alpine zone in the study transect usually begins near 11,000 feet. It rises to peaks 2,500 feet above timberline at only one point outside the Colorado Front Range and is less than 3,000 feet higher there. The altitudinal depth of the alpine zone in the two regions is thus comparable if we leave the high Cascade volcanoes out of consideration.

This peak stands 50 miles from the western edge of the Cascades and 60 miles from tidewater, surrounded by dozens of peaks of equal or greater magnitude. At its base the Skagit River runs at an altitude of only 500 feet, and can carry to the sea the detritus generated by this big and rugged terrain only because it is fed by heavy runoff from precipitation which is known to approximate 100 inches per year in such sites. To do even roughly equivalent work the less vigorous runoff from the study transect requires considerably greater gradients at any given distance from the headwaters of its streams. Furthermore, those ranges are far from the sea.

Streams draining the Rockies must therefore originate on plateaus which lie very high relative to range summits there. Local relief, which is 7,850 feet in this view, is a major tactical consideration. It is greater here and over much of the northern Cascades than in any part of the study transect, though absolute altitude is much greater there. Alpine peaks seen in this view are within easy reach of helicopter airlift, whereas those of the transect are close to the present operational limits of such craft.

Precipitation in the Cascades, like that of the moistest ranges of the Rockies, nearly all falls in autumn, winter, and spring. Summers are usually dry, with a high forest-fire hazard. Because the range is cloudy, moist, and mild, January and July mean temperatures at timberline differ by only about 25 Fahrenheit degrees. At transect timberlines the corresponding difference is nearly 40 Fahrenheit degrees, so that January mean temperatures there are generally near or only a few degrees above 10°F.

For reasons which are basically climatic, Cascade timber is much larger than that of the transect. Douglas firs in the Cascades are commonly 200 feet high and 6 feet through at the base. Sierra sequoias are commonly half again as high and are twice or three times as big at the base. Most coniferous timber in the Rockies, which includes many Douglas firs, is a fifth or a tenth as large as those of the Cascades. Except in burnt or logged areas, which are now very extensive, and on avalanche slopes, the Cascade forest is dense and essentially continuous below timberline, whereas the montane forest of the Rockies, in particular, is sparse and has many natural openings.

Sixty-five miles east of this site the Cascade forest ends at the lee margin of the range (Okanogan, Washington, 900 feet, 11.6 inches of precipitation per year). A semi-arid "intermontane" climate and vegetation become established there and these extend over vast areas to the south and southeast of that point between the Cascades, Sierras, and Rockies. Their mountainous aspect is represented here by Figure 2.

Figure 2. The Ruby Range, Nevada, September 1968. This range stands 11,349 feet above the sea on a 5,000- to 7,000-foot plateau, 200 miles west of Salt Lake City and 300 miles east of the Sierras. Few intermontane ranges are high enough to be compared very closely with the Rockies, but this view suggests that, level by level, environmental differences are not great.

The plateau here gets about 12 inches of precipitation per year. The range is known to get amounts in excess of 20 inches and presumably gets twice that much at its 10,000-foot timberline. Vegetation and glacial topography near timberline in this view are much like those of all ranges in similar latitudes which have similar precipitation regimes and height above timberline.

Figure 2. The Ruby Range

Pacific air masses which pass over the Sierras and Cascades have had most of the moisture wrung out of their lower layers by those ranges. In this view, a narrow band of open timber, much interrupted by cliffs, therefore gives way downslope first to chaparral similar at least in form to that of the Sierras and Wasatch, and then to sagebrush (Artemesia, called wormwood in the Old World, and associated desert scrub species). The sagebrush vegetation community is widespread on central Asian steppes, as well as on Rocky Mountain and intermontane steppe topography (basin floors) in this country.

Most intermontane ranges (those between the Cascades, Sierras, and Rockies) are considerably lower than the Ruby Mountains and, like them, lack drainage to the sea. Being lower, they generally have no timber except sparse pinyon pine and juniper, or other drouth-resistent pines, on a few crests. The Snake Range (13,058 feet), further south in eastern Nevada, is another exception to that rule, however. Precipitation which falls on the Basin Ranges is all re-evaporated and is then mostly carried eastward again to the Rockies by the prevailing westerlies. For that reason, and because of their general lack of height, the intermontane ranges can be said not to have very much effect on the character of air masses traversing them, and therefore on Rocky Mountain climate, particularly in comparison with the strong effect of the Sierra-Cascade crest.

III. The Wasatch Barrier

The uplifted eastern side of the Wasatch Fault forms a high and narrow mountain range extending about 125 miles north and 75 miles south of Salt Lake City. The fault scarp thus faces away from the Rockies toward the intermontane region and the Pacific. In its highest part the range rises to 11,750 feet and has 7,000 feet of local relief. It is about 15 miles wide east of the city, but is narrower elsewhere. As a military obstacle it is analogous to ranges in the Old World which are too narrow to shelter independent buffer states but, like the Pyrenees, have long been stable frontiers because of their effect on the operations of any large, closely organized, military force.

Because nearby settlements depend on Wasatch water, they cluster under the highest part of the mountains just as oases do under Central Asian ranges. Much of that settlement is within the latitudinal limits of the study transect. Within the transect, Provo and Spanish Fork canyons carry Routes 189 and 50 through the mountain barrier below 6,000 feet, as Weber Canyon does Route 80N just to the north. At Salt Lake City, Parley's Canyon carries Route 40 (now Interstate 80) through the Wasatch at about 7,000 feet. Such narrow low-level gaps serving a large population would be of great importance if the range were actually a military obstacle. Provo Canyon is therefore described more fully later.

Figure 3. The Wasatch Range at Salt Lake City, September 1968. The western base of the Wasatch, which is the line of the Wasatch Fault, also approximates throughout much of its length both the 5,000-foot contour and the old shoreline of Pleistocene Lake Bonneville. The shoreline is a level topographic bench visible here just above the domed roof. That level at the range base gets roughly 15 inches of precipitation per year, mostly in winter. That is somewhat more than falls on the basin floor away from the range.

John James' climatic maps demonstrate that the old shoreline level is somewhat milder in winter than levels either above or below and is less hot in summer than those below. The Salt Lake airport, about four miles from the nearest mountains, gets about 14 inches of precipitation per year, averages 56 days per year above 90°F, and has a mean January temperature of 27°. Night temperatures (mean daily minima) average 17.5° there in that month. The annual range of mean monthly temperatures at the airport is 50 F°.

Timberline in the Wasatch is about 10,000 feet above sea level and gets 50 or more inches of precipitation per year. Peaks reach 10,242 feet in this view. The timberline zone has no frost-free season, has absolute maximum temperatures in the low or mid 80's, and has few mid-winter thaws. Alpine climate in the Wasatch is considered quite like

Figure 3. The Wasatch Range at Salt Lake City

that of the high, relatively dry, eastern and southern Sierras. Its annual range of mean monthly temperatures is a few degrees below 40°F.

Sagebrush and grassland go almost to timberline on dry, sunny, Wasatch ridges, though not on the shady subalpine slopes in this view. Subalpine fir and Engelmann spruce (the subalpine vegetation zone) descend here to roughly 8,000 feet, interfingering broadly there with montane vegetation.

The term "montane" applies here to all plant communities characteristically found on mountainsides below the subalpine zone but not to communities characteristically widespread on level or nearly level ground at the same or lower levels. In the Wasatch, upper montane plant communities include remnant groves of Douglas and white fir (Pseudotsuga and Abies), stands of lodgepole pine, and stands of aspen. Especially prevalent in the lower montane zone is the oak-maple deciduous chaparral seen on the near slopes, where it characteristically breaks into circular clumps at its contact with lowland vegetation (various introduced grasses and herbs here, sagebrush elsewhere). Alpine meadow is extensive at timberline in the range but becomes sparse for lack of soil on high crests.

Figure 4. Little Cottonwood Canyon

Figure 4. Little Cottonwood Canyon, September 1968. This canyon heads above timberline on the Wasatch divide, so that it carries no through route. Its highway leads to Alta, a ski resort near timberline at its head. This is the only Wasatch gorge which ever carried glacial ice to the base of the range. Various other canyons have been similarly broadened by glaciers, but only in their upper parts. Debris from the Wasatch glacier system formerly descended many canyons to the shores of ancient Lake Bonneville and was then distributed along the lakeshore by waves and currents. Consequently, stony mountain soils now give way abruptly at that level to sands, gravels, and good agricultural silts.

Lone Peak, right, reaches 11,253 feet. The range here is of massive granite and relatively high grade metamorphic rocks. In this view and in Figure 5, the steepness of the range is minimized by views which look up sloping fan surfaces to the range base. The fans appear level but actually climb one or two hundred feet per mile.

Figure 5. American Fork Canyon, September 1968. This is the unglaciated mouth of a gorge which has been cut in sedimentary strata that are not strongly metamorphosed. However, the adjacent fault scarp (range front), and the canyon walls themselves, are not weathered back much more

Figure 5. American Fork Canyon

than those cut in somewhat more resistant rocks near Little Cottonwood Canyon, nor are they much dissected by lesser gorges. Mount Timpanogos, 11,750 feet, is whitened here by early snow. Cold air moving east over the Wasatch in winter and spring drains down these gorges to produce frequent strong breezes and occasional violent winds at their mouths (severe damage two or three times per decade). During a century since settlement, 300 flash floods have been recorded from such canyons, mostly due to thunderstorms in the range. Excessive grazing, logging and burning have permitted severe damage to both mountain and lowland soils west of the Wasatch crest by thunderstorm precipitation and floods. Forest is seen to have been severely depleted both here and in Figure 4.

Figure 6. The Alpine Zone near Alta, Utah (Little Cottonwood Canyon). Early June 1962. The climatic station at Alta (8,760 feet, at the canyon head) probably represents reasonably well the upper subalpine zone here, in which snowcovered meadow is seen to be extensive. It averages about 55 inches of precipitation and 450 inches of snowfall per year, has had 64 inches of snow in one storm, and has had a maximum of 180 inches (15 feet) of snow on the ground. Midwinter mean temperatures here are below 20°F and strong thaws are rare at that season. Most of the snow here will be gone in a month; none of it will last through the

Figure 6. The alpine zone near Alta, Utah

summer. The distant snow on the horizon lies on the alpine Uintas 40 miles east.

Winter occupancy here by miners and skiers has been greater than in most of our high western ranges, and avalanche damage and casualties have been proportionately heavy, though not heavy enough to seriously deter skiers. Forest Service avalanche studies have therefore been concentrated at Alta. Snow in the Wasatch is characteristically almost as deep, but much lighter, than that of rainy west-facing Sierra and Cascade timberlines, where the snowpack thaws throughout midwinter at its base.

The canyon floor here descends 5,000 feet westward in ten miles. Summits near the range divide at the canyon head are slightly less high than those near the range front (11,049 vs. 11,253 feet). This view emphasizes the especially steep north wall of the canyon. Spur

Figure 7. A timberline basin

ridges are longer and enclose extensive timberline basins (Fig. 7) on the south wall (right).

Figure 7. A Timberline Basin, early June 1962. Whereas slopes below the subalpine zone on the west flank of the Wasatch are ordinarily steep, or even cliffed, as in Figures 3 to 5, broad alpine benches (alp slopes) are common in that range near and above 10,000 feet (timberline). This

basin (a Pleistocene glacial source-basin or cirque) lies above the south wall of Little Cottonwood Canyon roughly halfway between its mouth and its head.

Ski or snowshoe trafficability is good here under favorable winter or spring conditions except across ridges, in especially dense conifers, and over the exposed coarse boulderfields along rock glacier margins (the lobes descending here from the right wall of the basin). (See Fig. 8.) Such barriers may require that skis or snowshoes be removed and carried, and may be an awkward passage particularly for people carrying skis. At other times, oversnow movement can be difficult and hazardous because of avalanche conditions, or because of soft, crusty, or icy snow.

Summer foot trafficability is excellent locally here but is slow on steep ground, in dense timber, or on coarse boulderfields. To the extent that cliffs exist around the rims of such basins they are not only a trafficability problem but could also force troops into defiles through which they could pass only one by one, or a few at a time. However, the alpine Wasatch is rugged only locally and cliffs are quite discontinuous on many of its crests, as in this view.

Figure 8. Brighton Basin, July 1962. View east. The ski resort of Brighton, 8,740 feet, is seen here on the main basin floor (cirque floor)

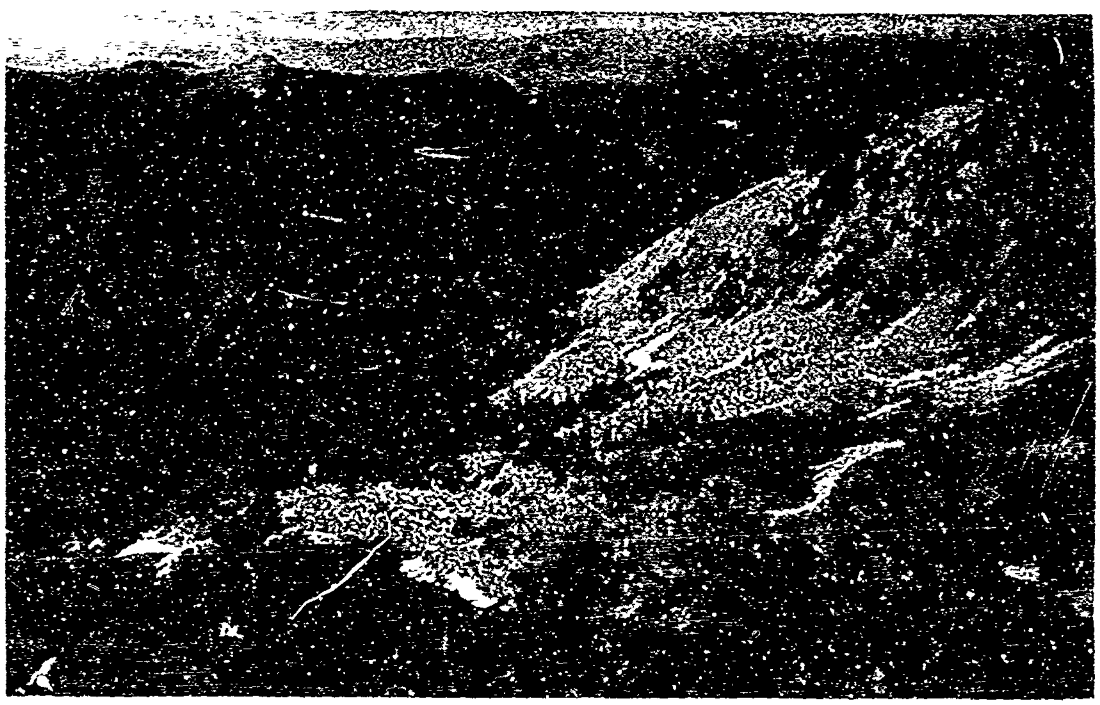
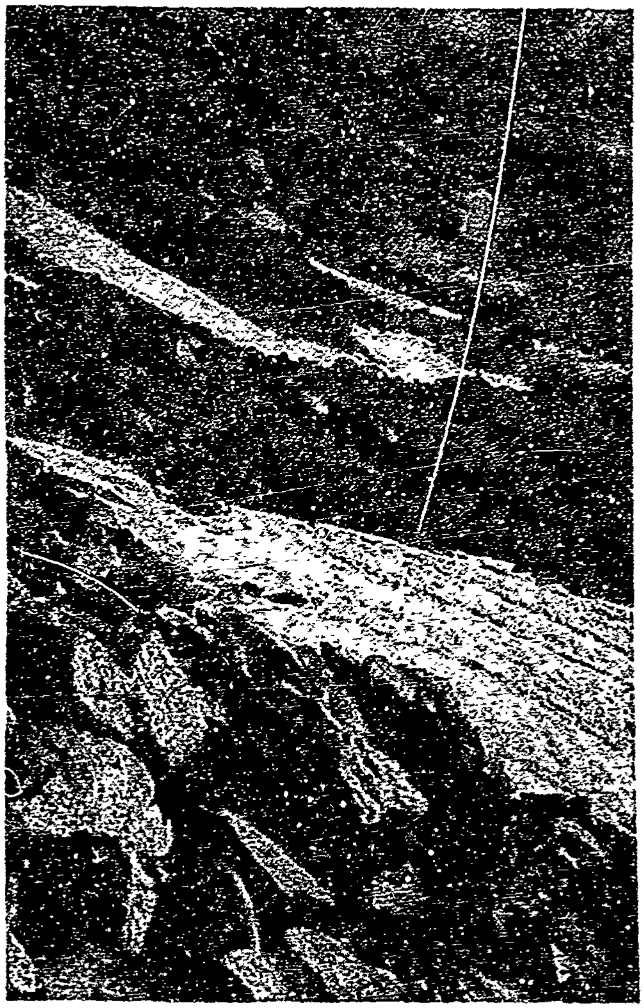


Figure 8. Brighton Basin

below and to the right of the reservoir. Precipitation is about 40 inches per year there and, as elsewhere in the high Wasatch, about 70% of it falls in winter. The forest is subalpine spruce-fir. The basin floor has never been warmer than 87°F during the period of record and has no frost-free season.



The soil-free boulderfield (felsenmeer) in the near ground overlies a deep matrix of permafrost in bouldery silt, which is icy enough to permit slow glacial flow. Talus or moraine material is thus reworked by gravity into "rock glacier" lobes, the snouts of which may be unstable and hazardous. Frost heave apparently sorts the upper layer of such masses, bringing a mantle of especially coarse soil-free boulders (the felsenmeer) to their surface.

Figure 9. Cliffs, talus, and rock glacier, Brighton Basin

Figure 9. Cliffs, Talus, and Rock Glacier, Brighton Basin, July 1962. The boulders of this felsenmeer are crystalline metamorphic rock. Crevices among them are chilly because soil-ice lasts through the summer in their depths. Nevertheless, with some labor, the larger ones could be made into good concealment and defensive positions for troops. Such boulders are laborious, but not dangerous, to march over except where they lie precariously on steep slopes.

The cliffs behind the boulderfields are not a serious obstacle to either individual climbers or small groups. Even the best routes through them do constitute defiles, however. To the narrowness and steepness of the gaps (cols) seen on the skyline here would be added the problem of rockfall set off by the first troops of a formation, endangering those behind. If only one man can pass such a gap per minute, a thousand men will take almost 17 hours to pass. Such barriers thus have a much greater effect on large unit mobility than on that of small, irregular, formations.

In early summer, late-lying snowfields such as those shown have become dense and are easily traversed during midday but freeze hard on clear nights so that steps would have to be cut to traverse their steeper parts, and ropes then used to prevent unchecked falls. By late summer, no snow remains in the Wasatch. The problem is much more severe and lasts through the summer in many ranges elsewhere in the world.

Figure 10. Alta Upper Cirque, September 1968. This terrain is quite similar to that seen in spring in Figure 7. A large military formation could be assembled in these trafficable meadows and in the open timber of this ancient glacial source-basin, or could be deployed and supplied on the rim of the basin from this point. Once in position, such a force

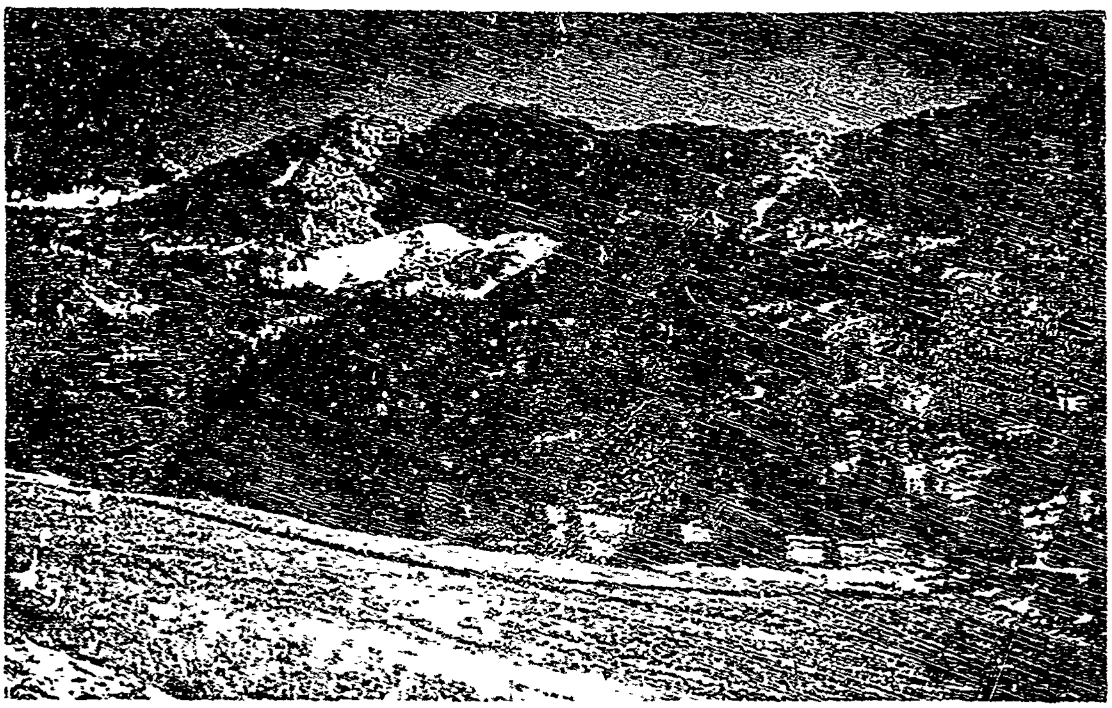


Figure 10. Alta Upper Cirque

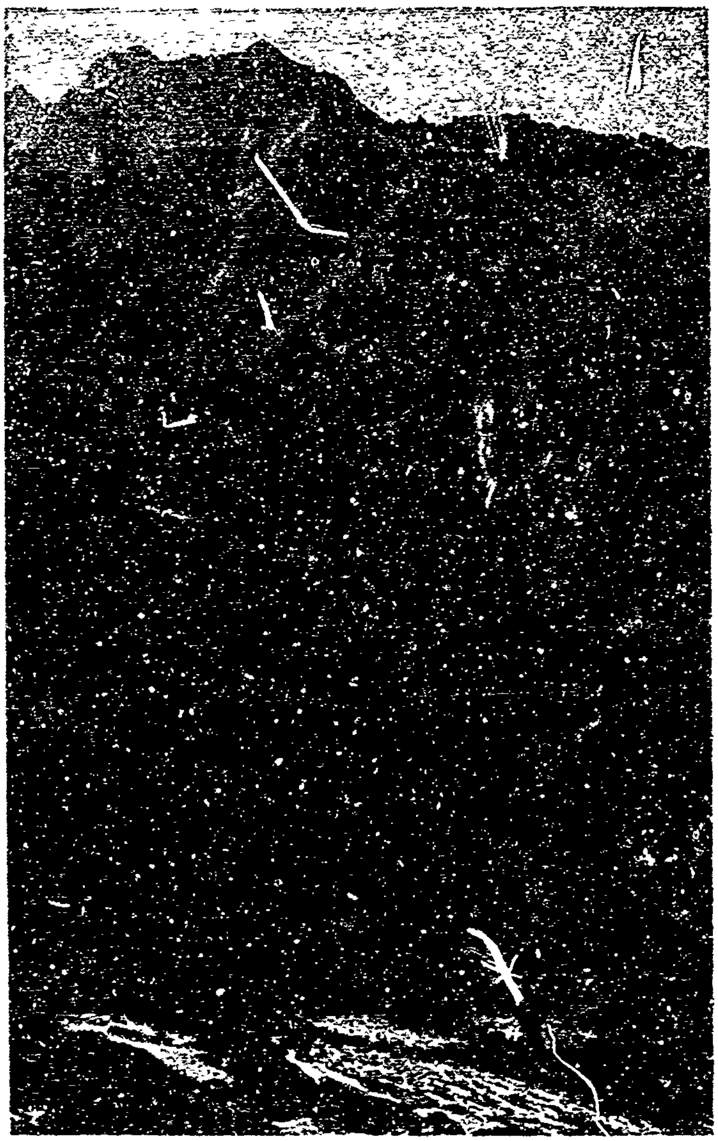


Figure 11. Avalanche slopes and steep timber, Alta.

would be hard to dislodge, but it could be encircled or overpassed by an airmobile force.

Defiles in the passes and cols of the rim of such a cirque, and downvalley also if the valley highway were blocked, would generally prevent overland movement of such a formation as a unit. Though these slopes are relatively smooth as mountainsides go, they are stony, and might cause a number of fractured ankles during the landing of any sizeable parachute force.

On the other hand, helicopter access to this 9,400 foot level is already good and will improve. For example, shortly before the 1967-68 ski season, a civilian Sikorsky S-61-A helicopter with a payload capacity of 8,000 pounds at sea level was used to install a number of 5,000 pound steel lift towers in the Alta system, the highest of which was at 10,000 feet.

Figure 11. Avalanche Slopes and Steep Timber, Alta, September 1968. Timber clearance, damage to timber, and landforms shaped by avalanche erosion (gullies, called couloirs, on the peak and an abraded slope in the middle ground), are photointerpretive and field keys to seasonal avalanche

hazard. The steep open slope here is heavily skied under favorable winter conditions but is very dangerous at times. Such slopes at Alta are regularly closed to skiing when avalanches are predicted. Because the snowslides tend to diverge from ridges before becoming dangerous, however, timber often persists on ridge crests and indicates a safe route of ascent under most conditions.

Military summary: the Wasatch barrier: The high Wasatch is not as favorable to irregular, as compared to regular, forces as a more rugged and extensive range might be, but it does illustrate the difficulties which prevent movement of massed troops on such ground. On the other hand, the terrain permits movement by small knowledgeable groups under favorable conditions even in winter. Aerial mobility would solve the basic problems of operation by regular troops in such terrain, but even so they would need experience in mountains if they were to suppress small unit enemy operations, such as road, water supply, and power supply demolitions, particularly at night, in storm, and in winter. Good understanding of trafficability problems and of natural hazards in mountains would be needed here both by operation planners and by troops in the field.

Figure 12. Shadow slope, Provo Canyon

IV. A Gap in the Wasatch (Provo Canyon)

From the Heber lowland and the Deer Creek Reservoir (5,500 feet) east of the Wasatch, the Provo River descends through a narrow canyon to Utah Lake (4,483 feet) west of the range, crossing the 5,000-foot contour halfway. Throughout the central five miles of the canyon, about a mile separates the 6,000-foot contours on its slopes, and two miles the 8,000-foot contours. Canyon wall crests are at 10,000 feet on both sides, and the Timpanogos massif exceeds 11,500 feet about three miles northwest of the gorge highway.

Figure 12. Shadow Slope, Provo Canyon, view southwest, early June 1962. The conifers are white fir (Abies) and Douglas fir (Pseudotsuga), giving way upslope near the current snowline to Engelmann spruce and alpine fir (the subalpine zone). Below the late spring snowline seen here, few slopes other than cliffs and outcrops are open ground. The grey tone on apparent open ground here is leafless oak chaparral (dense scrub much like Mediterranean maquis except that it is not evergreen). Montane vegetation here is quite characteristic of that of shady slopes at that level throughout the Wasatch. Use of the gap by highway, rail, pipeline, powerlines, and irrigation ditches, is well shown. All such services, as well as military communications, would be endangered by military operations in the gap or on the range.

Figure 13. Sun slope, Provo Canyon

Figure 14. Detail, oak scrub

Figure 13. Sun Slope, Provo Canyon, September 1968. Deciduous chaparral of oak, maple, and mountain mahogany shortly before losing its leaves. Maples are usually larger, globular, and lighter-toned here than other shrubs. Some grassy openings follow dry ridges. This is characteristic Wasatch vegetation on sunny montane slopes. Vivian Park resort is just to the left of the photograph.

Figure 14. Detail, Oak Scrub, September 1968. This vegetation, about 8 feet high, forms the shrubby matrix of the deciduous chaparral growth in Figure 13. It is excellent defensive cover. It remains a serious obstacle to movement in winter, but it then provides much less concealment.

Figure 15. A Still Drier Montane Slope, September 1968, above Vivian Park. Relatively open chaparral of oak (foreground) and mountain mahogany, about 6 feet high, with sagebrush and other low shrubs. A fir forest is opposite on a shady slope.

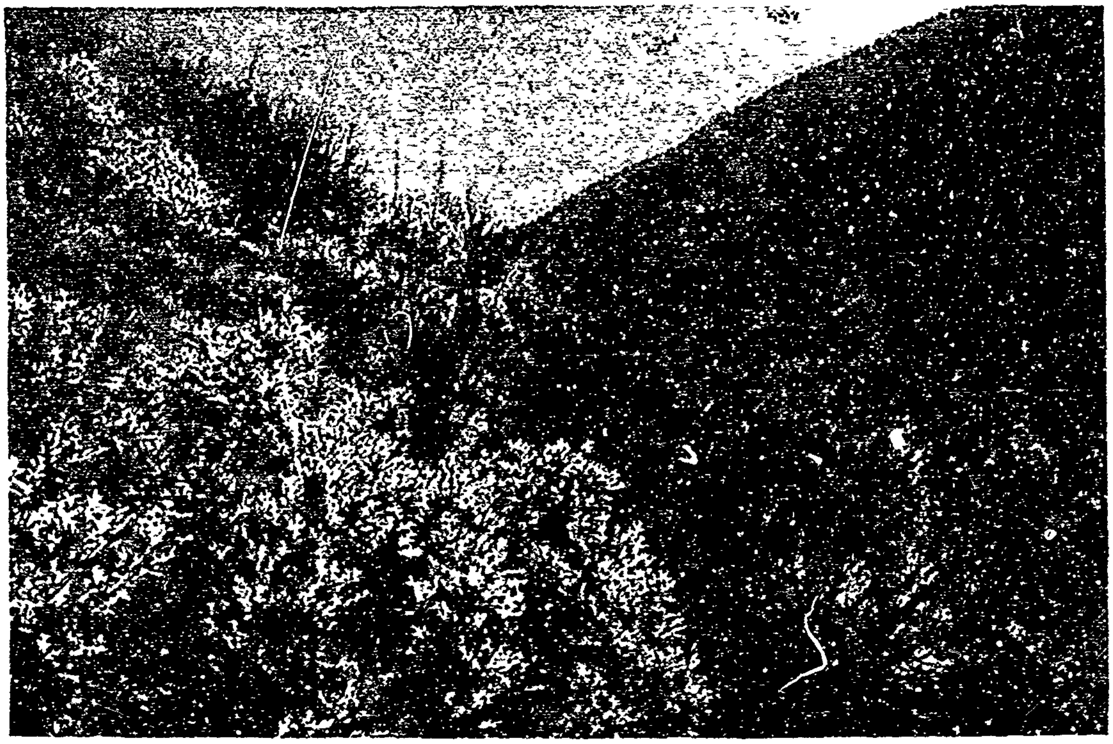


Figure 15. A still drier montane slope

Military summary: Provo Canyon. If such a passage could be occupied without resistance, the alpine Wasatch might be of little military importance. However, topography and vegetation would combine to make secure passage difficult to obtain against established resistance by even a few men.

V. The Back Valleys of the Wasatch

A zone of about 20 miles intervenes between the high Wasatch and the nearest timberlines of the Uinta Range to the east. In it valleys descend to 5,600 feet but are mostly higher. Hills exceed 9,000 feet in a number of places but lack timberlines. Precipitation is generally in the 15- to 30-inch range, falling mostly in winter, as in the Wasatch proper.

Figure 16. Timpanogos from the Heber flats, September 1968. These flats are at 5,600 feet and get 15 inches of precipitation. Timpanogos is 6,150 feet higher (11,750 feet). The fog bank marks the eastern mouth of Provo Canyon, from which it has emerged during the night. The foothills have oak-maple scrub, their foot slopes sagebrush. The high range has aspen, spruce-fir forest, alpine vegetation, and a light fall of early snow. Near Timpanogos the range is only about ten miles wide and would provide little room for maneuver by irregular forces. Nevertheless, small units might be hard to find in the montane chaparral, especially if they had many local sympathizers.

Figure 17. The Back Valley Zone, September 1968. A view across intervening hills toward the high Wasatch from near Francis, Utah, fifteen miles

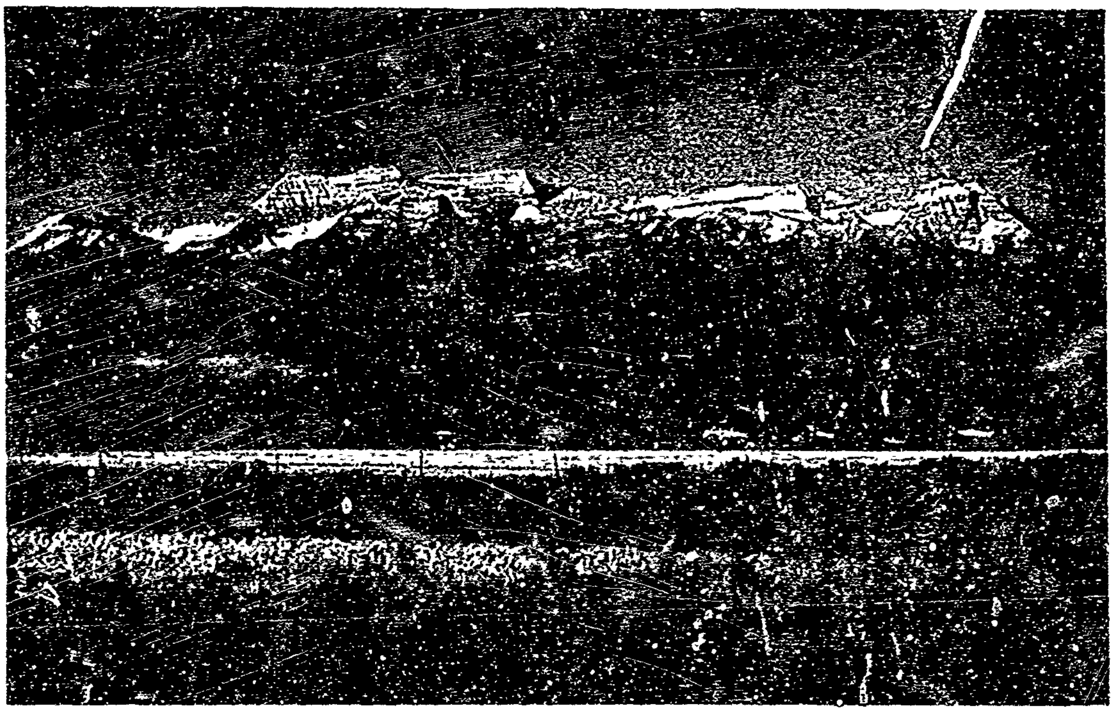


Figure 16. Timpanogos from the Heber Flats

Figure 17. The back valley zone

to the east. Bottomlands have cottonwood trees and hayfields. The rocky bench has sagebrush and some oak. The higher hills have oak-maple chaparral, with some aspen and fir or lodgepole pine forest. Notice that the montane conifers are confined to shady slopes.

Military summary: the back valley zone. Hills and oak chaparral are the main tactical and trafficability problems in the back valley area. Some defiles there might seriously delay troop movements if they were strongly defended. Nevertheless, the area would be a suitable landing area for an airmobile force overpassing the Wasatch, for example.

VI. <u>An Overview of the Uinta Range</u>

Beginning at a point 38 miles east of the high Wasatch, the resistant Precambrian quartzites of the Uinta Range stand continuously above an 11,000 foot timberline for 57 miles in an east-west direction. Kings Peak, 13,498 feet, stands almost 2,500 feet above that level. No road crosses the range in that distance. Nevertheless, because they lie parallel to the prevailing direction of the moist Pacific westerlies, and are in the lee of the Wasatch with respect to them, the Uintas seem to cause less uplift of such air, and to get less orographic precipitation from it, than do the Wasatch, which are nearly 2,000 feet lower. John James has therefore mapped the Uinta crest as having "over 45" inches of precipitation per year as compared with "over 55" in the Wasatch, yet data are scant and the estimate may even be high.

Eastward along the Uinta crest summer precipitation, largely from thunderstorms, is believed to become relatively more important as winter snowfall and total annual precipitation dwindle. That conclusion is supported by scanty and barely relevant instrumental data and by observation of late spring snow cover (Figs. 20 to 22 and much unpublished photo coverage). Pleistocene glacial erosion is also seen to have been much less vigorous eastward for lack of snow. Consequent topographic differences are of military interest. The range crest is much less sharp, and therefore more trafficable, in the east because of prolonged weathering of the upland surface, and incomplete glacial dissection. However, troops on the broad, boulderfield-mantled, summit domes there could easily find themselves half an hour or more from shelter in thunderstorm weather.

Beyond the ends of the continuously alpine Uinta crest, plateaus and isolated summits of the range descend gradually both to the Wasatch back valley zone westward and across the Colorado border southeastward. North and south the range steps down in less distance, first from an older summit-crowned erosion surface to a lower and younger one, then to canyons, and finally to broad irrigated basins eroded in poorly consolidated ancient (Tertiary) deposits. The alpine spurs and outliers of the range occupy a zone 15 to 25 miles wide centered on its continuously alpine part.

Figure 18. <u>Mt. Hayden, 12,475 feet, and Mt. Agassiz, 12,400 feet</u>, are seen here during July 1962 from the southwest at Bald Mountain Pass, 10,600 feet, the nearest road crossing west of the continuously alpine Uintas. Stony meadows and open subalpine forest occur throughout the range on very wide cirque floors, which have much less than the normal relief on such floors except where they are trenched by canyon heads. Uinta cirque headwalls are strikingly regular stratified rock walls separated from forested basin floors by talus and rock glacier.

In the valley between this point and the peaks, mean precipitation during three summer months totals 7.3 inches, leaving 30 inches to fall

Figure 18. Mount Hayden and Mount Agassiz

during the rest of the year, as compared with 4.5 and 37 inches at Brighton in the Wasatch. Pacific moisture is thus seen to be less important here.

Figure 19. Agassiz from Hayden, July 1962. Characteristic development of crests and basins in the more glacial parts of the western Uintas. The flat basin-floor gradients are typical. Most Uinta cliffs have much loose rock, but in a pinch these could be climbed at almost any point. Boulders on talus above rock glaciers (here largely snow-covered), and those on rock glacier snouts, are often dangerously unstable. Rock glacier motion has not everywhere been sufficient to form distinct lobes at the base of headwalls. On the other hand, a zone of well-developed rock glacier is continuous for several miles at many headwall bases, as in this view.

Figure 20. Spring Snowcover in the Glaciated High Uintas, view south, early June 1962. Lamotte and Ostler Peaks are to the left, 12,600 and 12,400 feet. Agassiz, Hayden, and other peaks rise to the right beyond the Stillwater Fork of the Bear River. The southern peaks of the Wasatch are seen about 60 miles away to the right. All this snow is seasonal, though it lies somewhat later than that of the Wasatch because of its greater altitude.

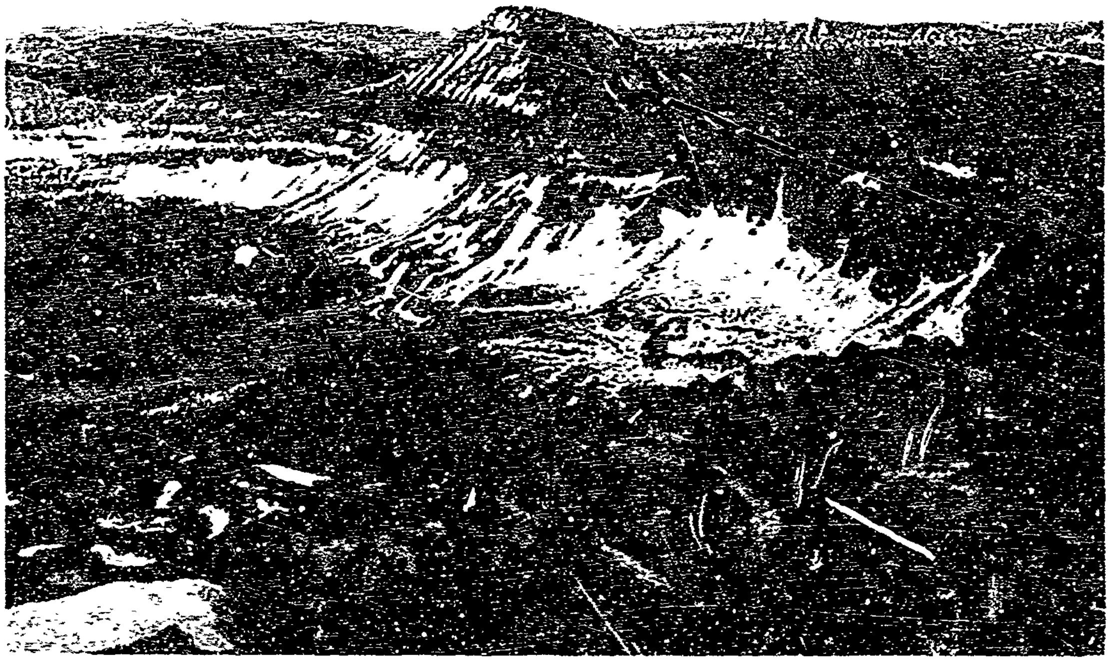


Figure 19. Agassiz from Hayden

Figure 20. Spring snowcover in the glaciated high Uintas

Figure 21. The Gilbert Peak pediment, Northern Uintas

Figure 21. The Gilbert Peak Pediment, Northern Uintas, early June 1962, view east. Landscape analysis in this locality by Wilmot Bradley in 1937 was critical to our understanding of such ramps as those seen here on the north flank of the range. Probable close analogs of these ramps in Asia are cited by Suslov and other Soviet authors as warped peneplains, a description formerly used for them in the Rockies.

The individual range-margin ramps here are relics of a continuous ramp (a desert pediment) developed under dry climate during the Tertiary period (prior to the ice ages) and later dissected by streams and glaciers. Pediments like the former continuous Uinta ramp are still being formed on the flanks of modern desert mountains, and have the appearance of the basin-floor surfaces in Figure 2. These ramps are believed to have been cut at about their present height and with their present gradient by occasional floodwaters descending high-gradient intermittent drainage lines. The erosional vigor of such floods tends to be exerted laterally rather than downward because of their heavy bed load, thus acting to plane rather than to dissect the surface. Tactical environment in the presence of such broad ramp surfaces is quite different from that in more uniformly broken mountain terrain.

Figure 22. The Two Major Pediment Surfaces, Southeastern Uintas, view north. The Pole Lake (Elkhorn) Plateau and Whiterocks Basin, early June 1962.

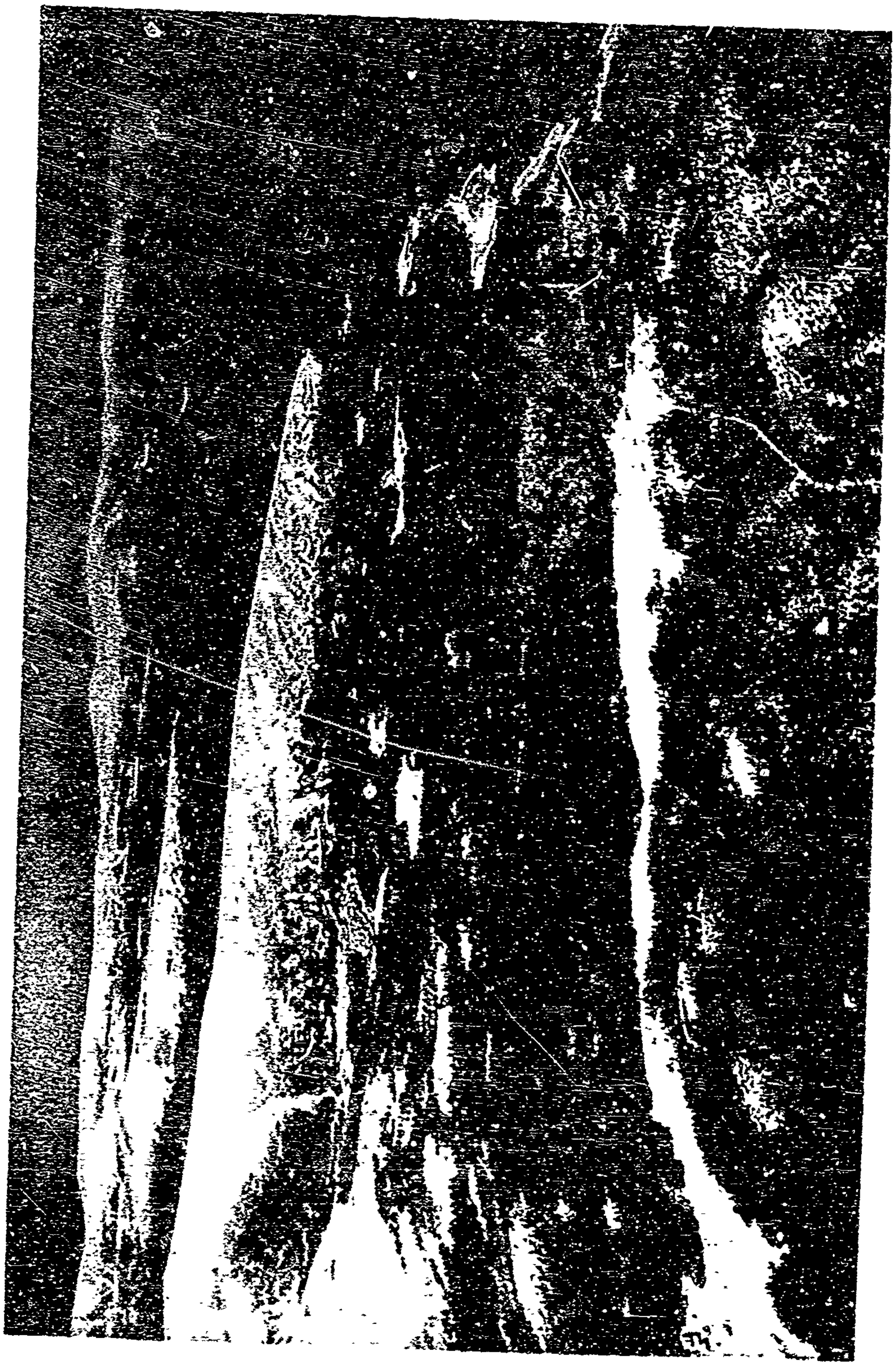


Figure 22. The two major pediment surfaces, southeastern Uintas

In the northern Uintas, two Tertiary pedimentation levels occur especially widely and were described by Bradley They are also clearly seen in this view on the south flank of the range, where a photointerpretive field check was recently made in support of this study. Range crests which once rose above the upper pediment level here have largely weathered away. The divide on the left skyline is at about 12,600 feet. Timberline is at about 11,000 feet.

Bradley called the two pediment systems the Gilbert Peak surface (upper and older), and the Bear Mountain surface (lower and younger). In this view the former is entirely alpine and the latter subalpine, with spruce-fir forest. Tertiary surfaces here were topographically less simple than the original Gilbert Peak surface once was in the area of Figure 21. They formed a basin which is now entirely occupied by the younger surface, and surrounding ridges to which it has still not attained. The Bear Mountain surface, having itself undercut the Gilbert Peak system, has since been undergoing dissection by Pleistocene canyons (the Whiterocks Canyon in this view, right), but has also gained area as the result of glacial cirque erosion at its upslope margin along the interpediment scarp.

Tertiary and Pleistocene development of the Bear Mountain pediment here as a system of broadened valleys has probably been much like that of the "pamir" pasturelands of the great range thus named in Turkestan. Those pasturelands are now subalpine or alpine meadows because the Pamir Range was uplifted during the Pleistocene along with Tibet, whereas Tertiary desert vegetation has been replaced at the subalpine level here by forest.

It appears here that much stream erosion has occurred in the Whiterocks Canyon since it was last occupied by ice, and that it has never been glacially eroded to the degree that the Duchesne Canyon has in the western Uintas, for example. The Ice Age glacial systems here were fed primarily by snow drifted from the bald Gilbert Peak uplands, and were therefore most active along the interpediment scarp, grading cirque floors there to accordance with little-modified pediment surface downslope at the canyon rim.

The result is a three-level topographic system The two graded surfaces (Tertiary pediments) which were cut on the Uinta quartzites, are separated from the broad lowland basins flanking the range by a range-margin scarp, which partly follows the contact of hard mountain rocks and soft lowland ones, but which has been rendered less simple by canyon-cutting in the margin of the quartzites below the Bear Mountain level. Within itself, the quartzite upland is traversed, as in this view, by the intricate interpediment scarp. It separates broadly interfingering Gilbert Peak and Bear Mountain pediment remnants, which are respectively alpine and subalpine in this view. In Figure 21, the Gilbert Peak surface was seen to slope northward into the subalpine zone all along the mountain front. Behind the camera here, the Bear Mountain surface similarly

descends from subalpine levels into the upper montane vegetative zone at about 9,500 feet, where it supports lodgepole pine forest and aspen.

As glaciers withdrew from the Bear Mountain surface here, their moraines, and the talus which then began to accumulate below their headwalls, formed permafrost, and in large part became rock glaciers which show various degrees of mobility and have sometimes developed lobate forms below the interpediment scarp. Snow-covered subalpine forest openings in hollows and along drainage lines in this view are ponds and bogs. Openings otherwise located which appear along the course of the access road are due to logging. The access road climbs the range front west of Farm Creek behind the camera position to avoid the narrow upper Whiterocks Canyon.

To the comment above that the Bear Mountain pediment surface in this view probably developed in much the same way as did the alpine grazing lands of the Pamirs, should be added the observation that the whole pattern of ridges and upland basins in the higher Uintas is suggestive of that of many of the lesser ranges of the high plateau of Tibet as they are seen in photographs by Gordon Cooper taken during the NASA Mercury program. Furthermore, the Tibetan ranges in question are probably much like many crests in the very dry eastern Pamirs, among which "pamir" subsummit surfaces are widely developed. Because the western part of the Pamirs gets fairly heavy precipitation from the westerlies, on the other hand, its glacial cover is heavy at high levels, its valleys are deep troughs, and its summits are sharp.

If the Uintas had been as greatly uplifted in Pleistocene time as were the Pamirs and Tibet, so that the whole Bear Mountain surface, as well as the Gilbert Peak summit uplands, were now well above timberline; if the Tertiary alluvial fill in the Uinta and Green River Basins had not been drained to the sea, and thus eroded, by major stream systems since its formation; and if shallow icecaps had formed on the range quite recently in geologic terms and spread downslope locally onto the Bear Mountain pediment, then analogy with certain Tibetan Plateau ranges would seem close indeed. Small areas of icecap having that relationship to Uinta-type summit and subsummit surfaces do occur in the Wind River Range in Wyoming.

<u>Military summary, Uinta overview</u>. Though the pediment system of the Uintas has been rendered less simple than it may once have been by Tertiary development and Pleistocene accentuation of a two-level differentiation of the surface of its central quartzite mass, and by Pleistocene basin and canyon erosion, the range remains a strikingly open landscape compared with most North American mountains. Large troop formations could move through it on foot, particularly in its eastern part, without being forced into many rigorous defiles. Because foot travel is slow on either of the two major pediment surfaces, however,

aerial mobility would nevertheless be very advantageous here. It would be even more so for regular Army operations than for irregular warfare.

It can be seen in Figure 22 that snowcover is not sufficient to fully conceal the windier parts of the weathered alpine Gilbert Peak surface. It would therefore be difficult ground for oversnow movement on foot. Within the sheltering forest of the subalpine zone, on the other hand, oversnow trafficability should be good in winter and spring.

VII. Uinta Surface Conditions and Trafficability

A visit to the Pole Lake Plateau in the southeastern Uintas (the area of Fig. 22) in September 1968 permitted further ground check and photographic recording of conditions previously seen only in aerial views or during brief visits further west in the range. Ground check of some kind is essential to photointerpretation, and photointerpretation is essential to sound operational planning in mountain terrain. In dealing with ranges in countries now inaccessible to us, however, we must use the method of analogy. That is, if the photointerpreter knows continental mountain environment in the Rockies, it will be much easier for him to interpret comparable landscapes in mid-Asia.

Figure 23. The Gilbert Peak and Bear Mountain Surfaces, September View. A view northwest toward the 12,600-foot Uinta divide from the 12,200-foot level on the crest of the Pole Lake plateau. The apparent smooth surface of the summit uplands on the skyline (the Gilbert Peak surface) actually has a texture similar to that of the felsenmeer in the foreground, in which the larger boulders are 3 to 5 feet across. Spruce-fir forest covers the Bear Mountain pediment, which has been extended upslope relative to its Tertiary position by Pleistocene glacial cirque erosion. Its drainage lines are boggy meadows.

Figure 23. The Gilbert Peak and Bear Mountain surfaces

Figure 24. View west, same time and place

Figure 24. View West, Same Time and Place. The Uintas are somewhat higher and have been somewhat sharpened by ice in the direction of this view. One of the distant summits is Kings Peak, 13,498 feet. Formation of clouds in the upper air westerlies over the more heavily glaciated Uintas is characteristic, and is believed to be associated with somewhat greater precipitation and snow cover there.

The snow in the foreground is a drift formed during an early autumn storm, caught between two big lobes of slowly sloughing felsenmeer-mantled soil the shape of which is not well seen in this view. Such solifluction causes occasional rockfalls down the glacial headwall to the right. If possible, ascent of such cliffs should therefore be along well-defined ridges such as those in the middle ground, especially during periods of strong thaw to the uplands. Notice that a number of quartzite slabs have been pushed into an erect position here by the soil movement.

Figure 25. Slabs Pushed Erect by Solifluction. A photograph from the 1966 University of Colorado report on the transect, taken by John James during the summer of 1965 or 1966 on Leidy Peak in the eastern Uintas. Heavy lichen growth indicates that the rocks seen here have stayed on the surface of the slowly creeping boulderfield for several centuries.

Figure 26. Polygons on the Pole Lake (Elkhorn) summit upland, late September 1968. View south from 11,500 feet toward the Uinta Basin

Figure 25. Slabs pushed erect by solifluction

Figure 26. Polygons

([illegible],000 feet). Like the lobate form of gross solifluction discussed above, the patterns seen here are a common Arctic phenomenon, generally associated with permafrost. The 10,600-foot forested crest seen downslope, like the foreground, is on the Uinta quartzite The relatively low altitude of the basin floor beyond, except for the 7,300-foot remnant butte, is due to rapid downwasting and erosion of poorly consolidated sediments from the range; the sediments were deposited in Tertiary time, when desert climate prevailed and streams were weak. Pleistocene climate greatly strengthened the stream system, particularly during glacial (pluvial) periods.

Figure 27. Polygon detail. View upslope. Each polygon has a veneer of soil in its central part, made up of windblown dust, roots, and other organic material, and carrying tundra species a few inches high. Where solifluction is relatively rapid, this pattern is often elongated to form striped ground. The scale of the pattern here (about 30 feet across) is of the order of magnitude characteristic of such patterns in the Arctic.

Though crevices are open beneath it, walking is easier on the central veneer of soil; striped ground thus provides paths advantageous for travel directly up or down hill. However, the soil-free blocks were also quite firm underfoot in the late season and are probably fairly stable year-round on this gradient as far as foot travel is concerned. Summer roads have been constructed and maintained with little difficulty across such uplands elsewhere in the Rockies and in New Hampshire, since permafrost is present under them only to a shallow depth above bedrock. There is much silt, useful as roadbed, only a few feet down among the stones. Regular operation of grading equipment takes care of disturbance due to solifluction on such slopes.

Figure 28. A Rock Glacier Near Pole Lake, September 1968. Particularly active rock glaciers have been found to move as much as several yards in a year; this one presumably moves much more slowly However, boulders on its front seem quite unstable, and an approach to the crest of the slope from above demonstrated that the boulders on the cliff above the mass are also quite unstable and hazardous. On such active cover, lichens are scanty or absent. Dark grey coloration of stable boulderfield surfaces in aerial views, or observation of relatively heavy lichen cover at close quarters, are indicators of routes which creep only slowly and would be safe for troops. On the farther cliff several boulderfield masses are being slowly fed over the precipice by solifluction. They are seen to contain much bouldery silt under a cover of open-jointed blocks (felsenmeer).

Figure 29. Stony Forest Floor, Pole Lake (Elkhorn) Plateau. Glacial moraine deposition and subsequent solifluction, have distributed quartzite boulders in irregular patterns on the Bear Mountain surface even at considerable distances from present cirque headwalls. Elsewhere

Figure 27. Polygon detail

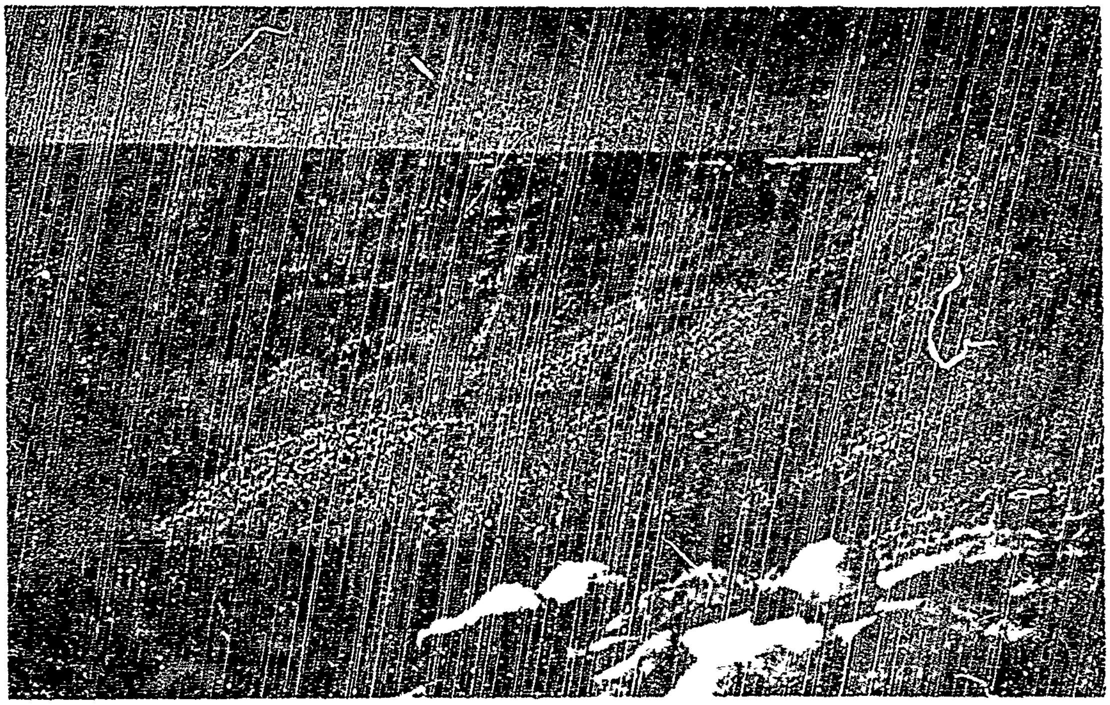


Figure 28. A rock glacier near Pole Lake

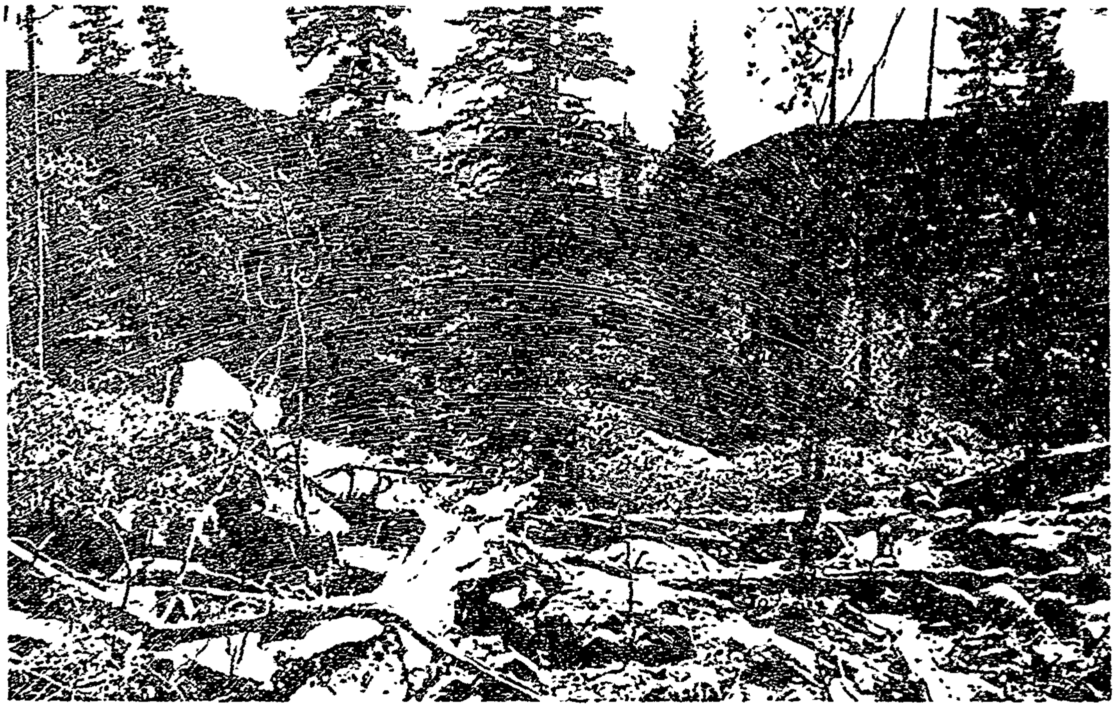


Figure 29. Stony forest floor

trafficability through the forest on foot is at least locally quite good except for a few windfalls. Such differences in forest trafficability are not easy to determine from airphotos. In general, montane lodgepole pine forest and aspen stands in the Uintas seem less obstructed than the subalpine forest. Whiterocks Canyon forms the background of the view.

Figure 30. Aspen on the rim of the Pole Lake plateau near the Farm Creek road, September 1968. Aspen windfalls decay fairly rapidly and therefore have somewhat less effect on foot movement than do conifer windfalls. The leaves seen here in evening sunshine were bright yellow and fell a few days later. In summer they are light green. It would be important to military operations here in spring that snowcover under aspens gets almost full winter and spring sun and thaws much earlier than snow under conifers.

Figure 31. The Farm Creek Scarp separating the Uinta Range (behind the camera) from the Uinta Basin (distant), September 1968, view south. A relatively dry montane landscape; sagebrush is extensive on slopes at the same level just outside this view to the left. Aspens tend to grow as roughly circular clumps, advancing outward by vegetative reproduction on their margin. They usually form stands of more or less uniform age, or in the western part of the study transect may comprise one fairly well defined

age-class of relatively large trees plus a new generation of young trees, as in Figure 30. Other undergrowth is usually scant beneath them.

Figure 30. Aspen

Further military comments on the Uintas: Trafficability of the alpine or subalpine interpediment scarp separating the Gilbert Peak and Bear Mountain levels on the Uinta quartzite is quite variable even in the southeastern Uintas. It is even more variable in the more heavily glaciated parts of the range, which have more cliff (Figs. 18 to 21), and is best in either case where the gradient of the scarp is seen on airphotos or maps to be relatively low.

Foot movement is laborious, but is not characteristically channeled into defiles, on boulderfields above and below the interpediment scarp. Troops on the alpine uplands would be severely exposed to weather, including thunderstorms, and should give themselves time to retreat unless satisfactory shelter is on hand against lightening, rain, snow, and wind. They would also be badly exposed there if the enemy controlled the air. Road construction, or availability of helicopter airlift, would greatly increase troop mobility in the Uintas.

Figure 31. The Farm Creek scarp

VIII. The Uinta Basin

The poorly consolidated alluvial material which was deposited on the flanks of the Uintas during Tertiary erosion of the range has since been greatly downwasted, as have most such weak Tertiary deposits throughout the central and southern Rockies. Irrigated agriculture and other human activities in the Rockies are largely concentrated in the broad basins thus produced. There is a difference in kind between such basins in the Rockies which are drained by very long rivers to the sea, and basins such as those of the intermontane region which have not been re-excavated because their drainage is short and internal.

The same contrast occurs in mid-Asia between moderately dry regions which are drained to the sea, or to interior basins at a great distance, and drier ones which, like much of our Great Basin physiographic province, were drained only by relatively short and weak streams, many of which ended in undrained basins even during Pleistocene pluvial times. Contrasting erosional histories can be expected, for example, in basins north and south of the divide between Siberia and Mongolia in the Altai and Sayan ranges. In Tibet some basins are deeply re-excavated and others are not, but uplift of the region has caused streams to work headward more or less rapidly into the unexcavated basins, insofar as they have enough moisture to support active drainage.

Figure 32. Irrigated Agriculture west of Roosevelt, Utah, 5,106 feet, September 1968, view northwest. Roosevelt gets only 8 inches of precipitation per year, but is far enough west in the Uinta Basin to record an autumn rather than a summer precipitation maximum (October 1.21 inches, December 0.81). January and July mean temperatures there are 15.2 and 71.4°F, the difference being 56 Fahrenheit degrees. Uinta runoff fills the canal, which is considerably above the level of the fields beyond it. Beyond the fields are old structural and stream terraces dissected into badlands. Farms, irrigation ditches, fences, and highways are the main changes here from the tactical point of view since such terrain was familiar to the Army during the Indian wars.

Figure 33. Pinyon-Juniper Woodland at 6,800 feet on Route 208 northwest of Duchesne. Table Mountain, 10,015 feet, is on the skyline. This view is upslope to the west over a sequence of successively older pediment levels. Cut during the Pleistocene in weak Tertiary beds, they record dry interglacial intervals in Pleistocene time. Such relatively recent pediments should not be confused with the Tertiary hard-rock pediments of the high Uintas. They originally merged downvalley into a system of stream terraces of corresponding age such as those seen in the middle distance in Figure 32. Dissection has produced canyons in the pediment surfaces and badlands on terrace margins.

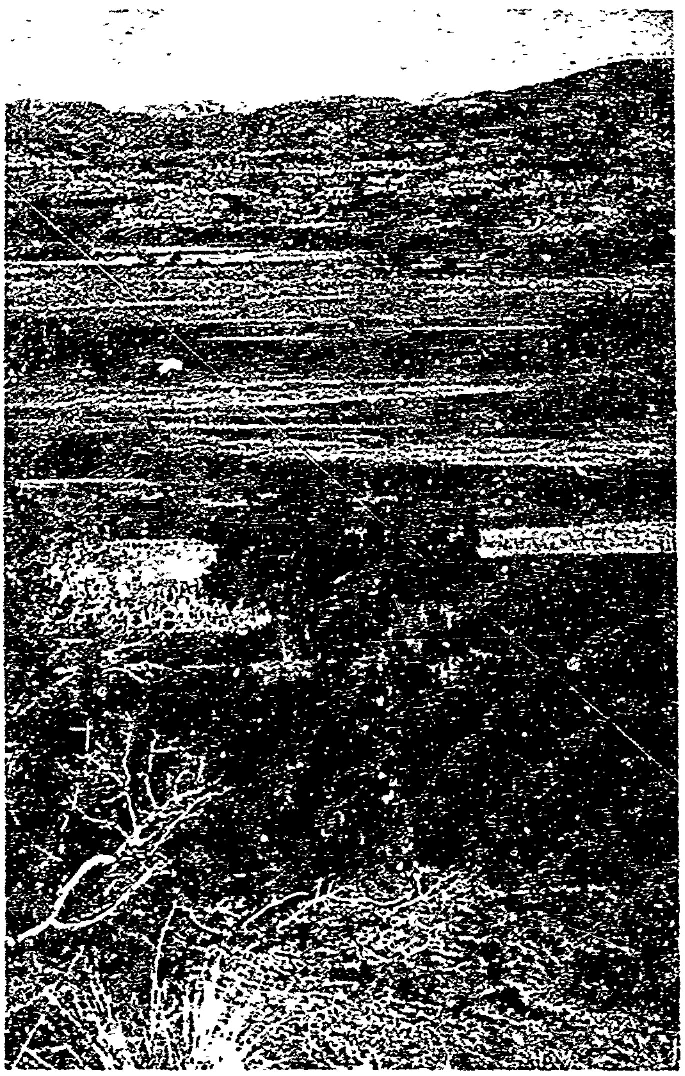


Figure 32. Irrigated agriculture

Pinyon-juniper occurs as a lower montane vegetation community on mountain footslopes and hills throughout the Uinta Basin and elsewhere in the study transect. It seems to occur under climatic conditions which might be equally favorable to deciduous oak chaparral. Possibly the chaparral occurs where pinyon-juniper has been persistently burnt, either recently or during Indian times. Chaparral is sparse, or more generally lacking, in the Uinta Basin, but is present both to the east and to the west. From the tactical point of view, the difference between the two vegetation communities is great: pinyon-juniper is consistently open and highly trafficable, whereas oak chaparral can be almost impenetrable.

Fruitland, a few miles west, probably represents pinyon-juniper climatic environment fairly well. It is at 6,680 feet and gets 12.8 inches of precipitation per year. Duchesne, at 5,520 feet a few miles east, gets only 9.5 inches of precipitation, with an August maximum and a 53 Fahrenheit degree range of mean monthly temperatures. July afternoons there average 85.8°F.

Figure 34. Sagebrush (Artemesia and associated species) is seen here on alluvial soils at 6,800 feet on Route 40 (middle ground) near

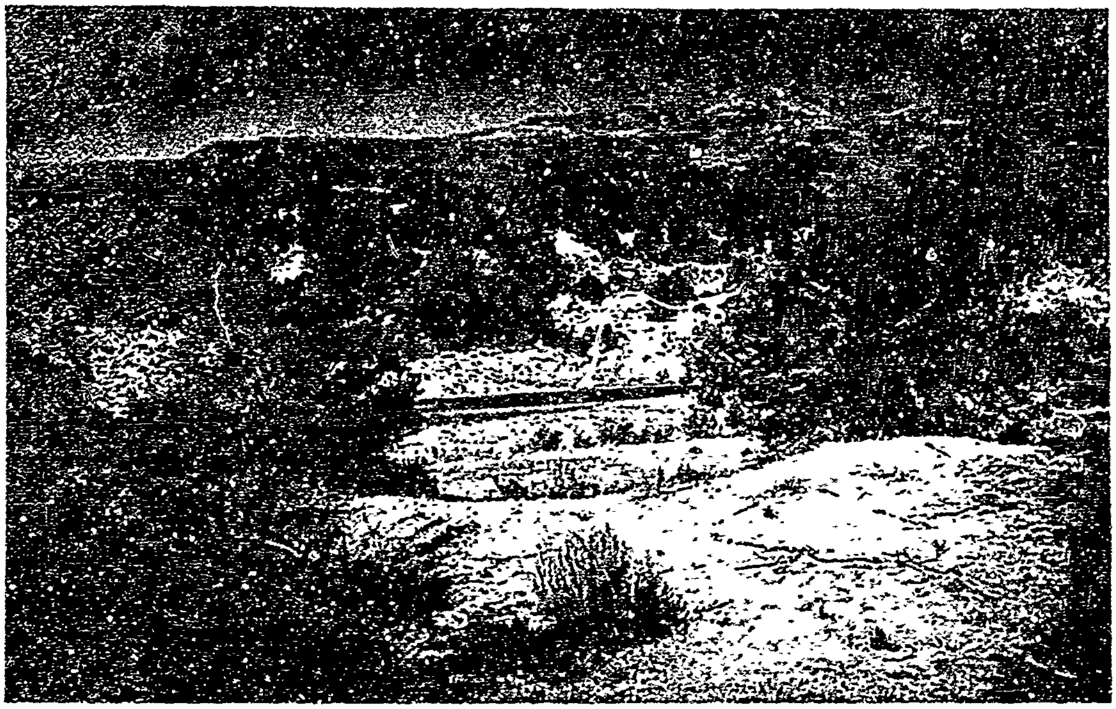


Figure 33. Pinyon-Juniper woodland

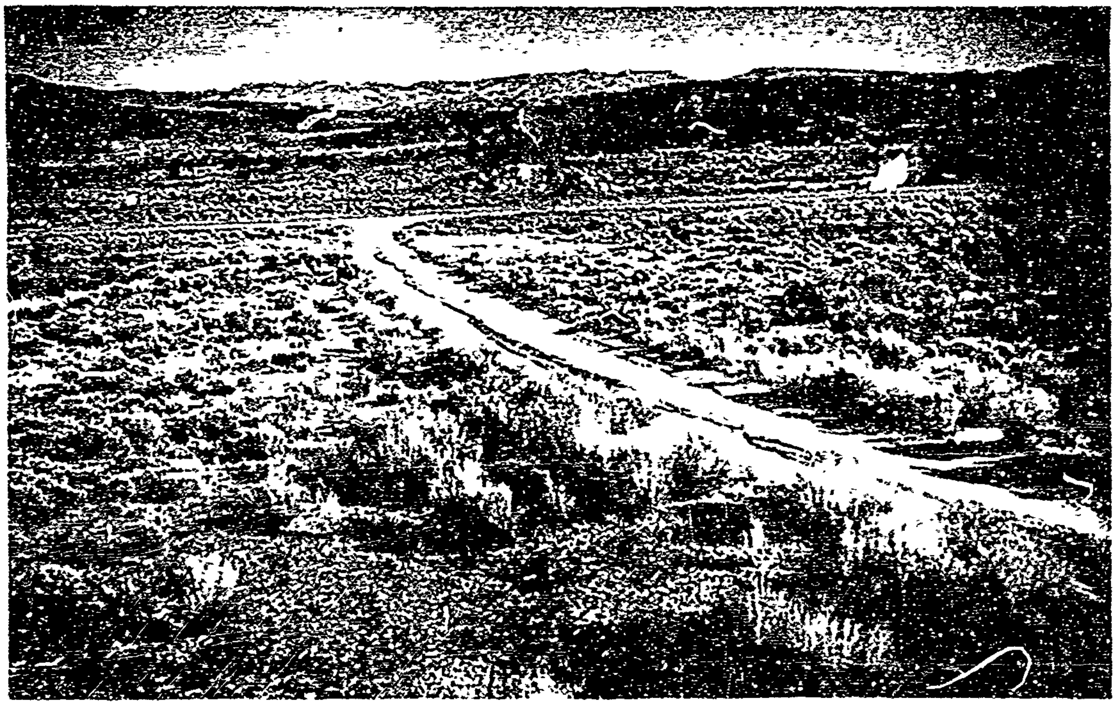


Figure 34. Sagebrush

its junction with Route 208 west of Duchesne. View northeast. Pinyon-juniper is confined here to outcrops and rocky ground, in the crevices of which its deep roots reach water unavailable to sage. The sagebrush, on the other hand, takes up practically all the water which falls on the alluvial soil. Such soils are normally never wetted to depth, and have a zone of accumulation of calcium or other salts (caliche) near their limit of wetting.

Such relationships, worked out in analogous environments by ecologists, soil scientists, and others, can be observed on aerial photographs, and provide information of considerable military and engineering value.

Figure 35. Badlands cut in weak Cretaceous structures of the easternmost Uinta Basin near Rangely, Colorado (5,270 feet), a center of oil production. The severely stunted vegetation to the left is that characteristic of oil shale outcrops in the vicinity. View east.

Military summary, Uinta Basin: As is usual in desert terrain, trafficability in the Uinta Basin is excellent in general, though irrigation ditches and badlands would present some problems.

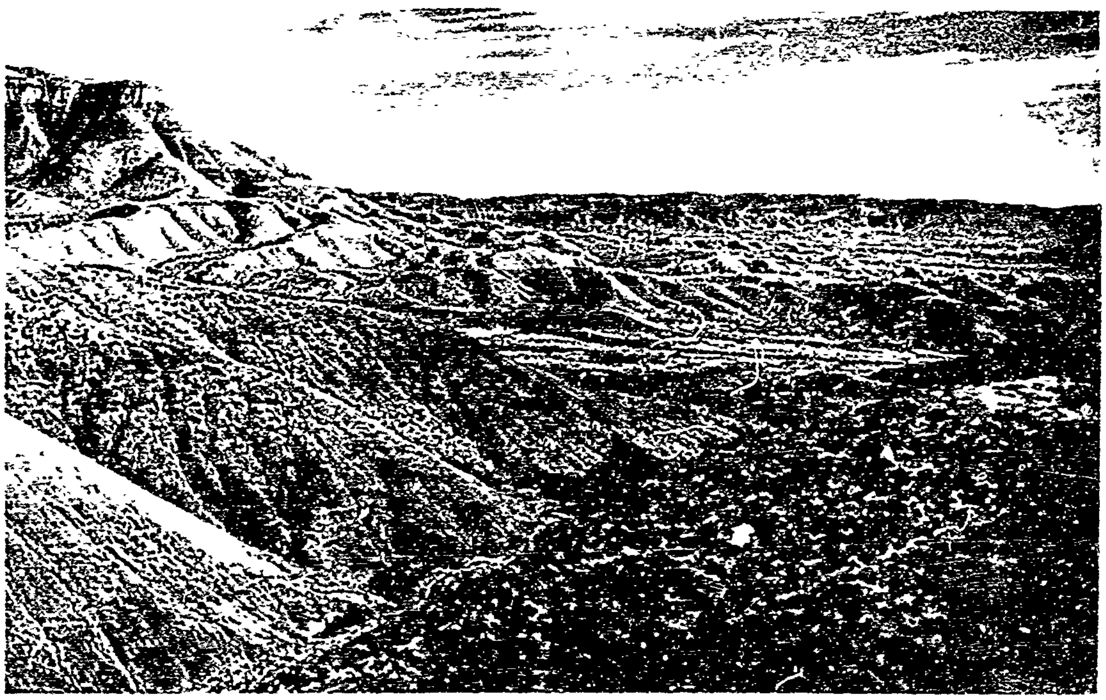


Figure 35. Badlands

IX. The Non-Mountainous Yampa Watershed

The Yampa watershed in Colorado, which is partly bordered by mountains, has a large area of low relief which presents few really critical problems from the tactical point of view. However, it is part of the study transect, and illustrates certain features of mid-continental plateau and range relationships which probably have analogs in central Asia. The area discussed here lies entirely upstream from the gorge which the Yampa has cut across the structures of the low eastern Uintas in northwesternmost Colorado near its junction with the Green River. The rolling plain of the central Yampa basin above that gorge lies on weak Tertiary rocks of the same age as those of the Uinta Basin. The Yampa basin has only a few hundred feet of local relief, though almost all of it lies above the 6,000 foot contour. Above Juniper Mountain (108°W), the center of the basin is largely avoided by the Yampa River for reasons which will be discussed.

Figure 36. Incision of the Meandering Channel of the Yampa River into the Uinta Anticline, Bear Canyon, Dinosaur National Monument, April 1964. View northeast. The canyon is somewhat more than 2,000 feet deep, cut in Carboniferous quartzite, which is less resistant than the Precambrian

Figure 36. Incision of the meandering channel of the Yampa River into the Uinta anticline

quartzite of the high Uintas. It records the former depth and subsequent downwasting, both upstream and downstream, of Tertiary fill in the Yampa and Uinta basins. The fill once covered, or lapped onto, the structures which are now exposed here, and the meander pattern of the river was then developed either on its surface or on plains cut by the stream along the margin of the fill. The whole volume of sediments since eroded from the fill by the Yampa River and its tributaries has passed through this gorge, yet the river has been unable to free itself from the meander pattern. It is of some tactical significance that the Yampa, and similar plateau streams elsewhere in the world, thus tend to become trapped in gorges in relatively resistant rocks as their temporary erosional base level is lowered by erosion downstream.

Conifers in the upland surface in this view are mostly pinyon-juniper, occurring between the 6,000 and 8,000 foot levels, whereas the river is near 5,000 feet. Sagebrush appears as a lighter grey tone. The snowcovered summit is Zenobia Peak, 9,006 feet.

Figure 37. Gorge of the Yampa in Cross Mountain, 7,800 feet, April 1964. View northeast. The great downwasting in Pleistocene time of the broad surface of the Yampa River basin is again dramatized here. The course of the river, now at 5,800 feet, originally lay on a plain near

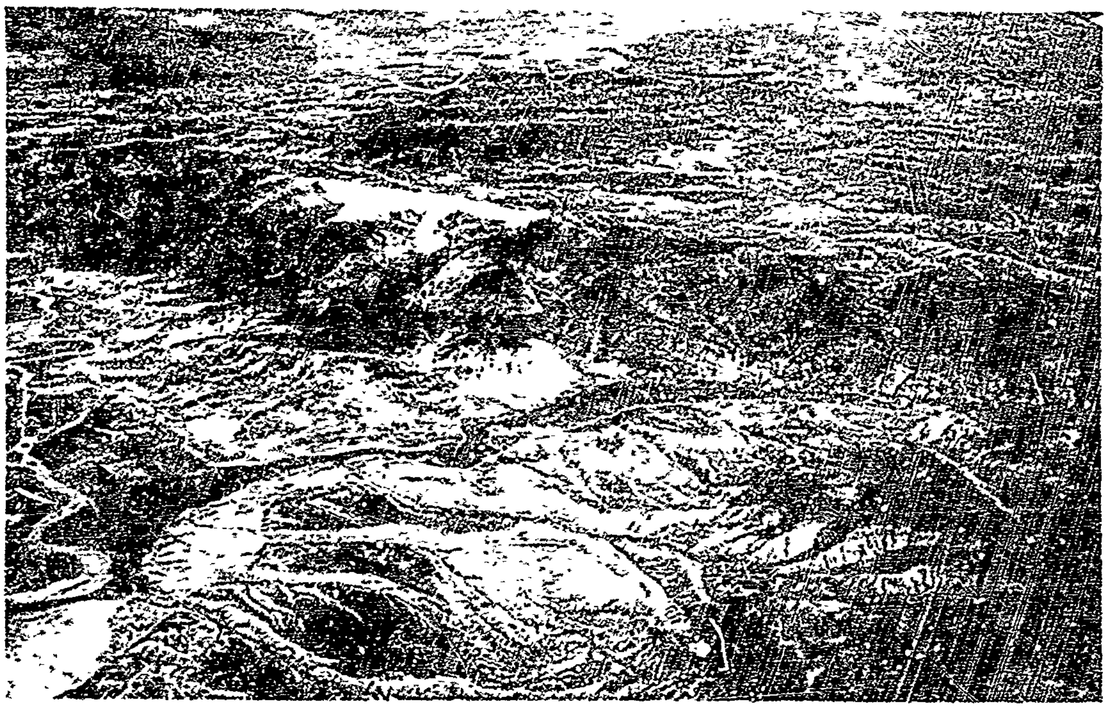


Figure 37. Gorge of the Yampa in Cross Mountain

or above the crest of the mountain, into which it is now incised more than a thousand feet to the right of center in this view. Weak Tertiary beds have been eroded by that amount not only around the whole circumference of Cross Mountain but along 65 miles of the northern half of the study transect and over a similar area in Wyoming, all the sediment passing down the river. Much of the area has been reduced to a rolling plain.

Wherever the Yampa has been let down by erosion onto beds more resistant than the Tertiary sediments, as it has here and along much of the southern margin of its basin, it has become intrenched and has had to stop shifting laterally across the basin floor Thus the river now no longer traverses much of the plains it has cut in the Tertiary formation, but lies for considerable distances somewhat below their level, so that the plains drain into hills near the river

Route 40 passes Cross Mountain to the south (right in this view), and crosses the Yampa as directly as possible where it still lies in open terrain on Tertiary beds. Beyond Juniper Mountain it strikes out eastward across the rolling plains developed on those beds earlier in the Pleistocene, following a minor drainage and an even less conspicuous minor watershed (Fig. 38). In that area military movement would similarly avoid, if possible, the line of the main drainage of this region.

By its open texture, the dark coniferous vegetation on Cross Mountain is seen to be pinyon-juniper woodland. Sagebrush covers the remnants of plain within the badlands in the foreground. The Little Snake River joins the Yampa in the left foreground, having approached it around the north end of Cross Mountain, along the left margin of the view.

Figure 38. Sagebrush-Covered Rolling Plain in an interfluve position west of Craig, Colorado, September 1968. View northwest. Because the Yampa and other main drainages no longer shift back and forth across it, but tend to be locked in trenches cut in more resistant beds to the south, the general surface of the Yampa basin west of Craig has had time to develop several hundred feet of rolling relief Because it is on weak materials, however, it is still rather featureless though there are areas of badland. Fields seen to the left are wheat stubble. Two alignments of Route 40 run along a minor divide, diagonally across the middle of the view. A pattern of sun and cloud shadow lies over the area. The altitude here is about 6,300 feet.

Figure 39. The Yampa River in Hills west of Hamilton, Colorado, south of area shown in Figure 36. View southeast The hills are the Cretaceous Williams Fork and Illes formations. Much of the plain represented by Figure 38 lies higher than the river does here among the hills nearby, and drains to it through them, as Milk Creek does here from the similarly weak Mancos Shale of the Axial basin to the south. Vegetation is largely sagebrush, with some wheat fields, partly plowed in September 1966 and

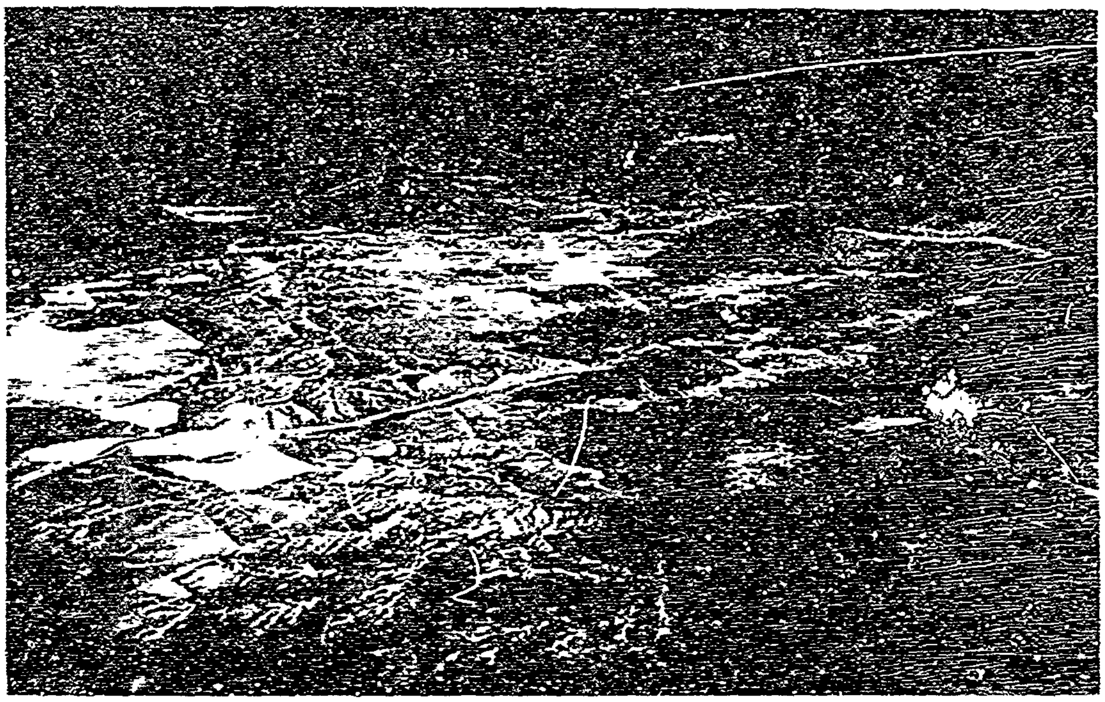


Figure 38. Sagebrush-covered rolling plain

Figure 39. The Yampa River in hills

with both oak chaparral and pinyon-juniper on hilltops. The stream is at 6,100 feet, the hills reach 7,200.

Figure 40. The Williams Fork Mountains, October 1964. View southeast. These hills are mountains only by local usage, since they reach only 8,200 feet of altitude above a stream running at about 6,400. Furthermore, a range in Middle Park is mapped under the same name. The picture is included to show the variety of hill forms encountered. It might be of tactical concern that the watershed of this range is displaced several miles to the left (north) of its topographic crest. Vegetation and geologic formations are as in the previous view.

Hamilton, which is at 6,235 feet on the lower Williams Fork River, equidistant from area in Figure 39 and 40, gets 19 inches of precipitation per year, with wet months in December (2.45 inches) and March (2.27 inches).

Figure 41. The Yampa Valley near Craig. View northeast, 6,188 feet, October 1964. Craig gets 14 inches of precipitation per year, with no distinct precipitation season. January averages 15.5°F, July 66.2°F, the difference being 50.7 Fahrenheit degrees. July afternoons average 86.3°F.

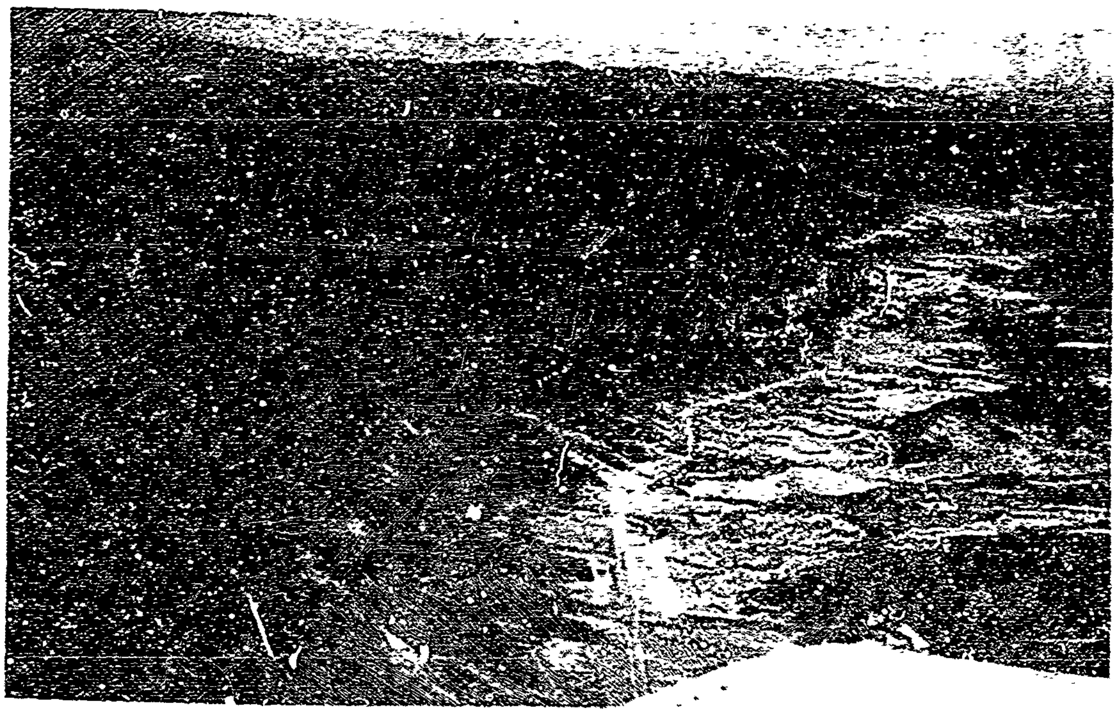


Figure 40. The Williams Fork Mountains

Figure 41. The Yampa Valley near Craig

Sagebrush and spring wheat are seen on the gently sloping hills, which are on Tertiary beds; cottonwoods and irrigated agriculture occupy the flood plain. Less regular hills on Cretaceous sediments rise to the right outside this view (southward) toward the Williams Fork Mountains. From this point east the relationship between drainage and topographic relief reverts to normal and Route 40 can therefore follow the river upvalley (eastward) to Steamboat Springs, where it crosses the Park Range.

Figure 42. The Steamboat Springs Basin, looking south toward the headwaters of the Yampa near the White River Plateau, over 12,000 feet high, which has fresh snowcover about 25 miles away on the horizon to the right. The town is at the bend of the river at 6,770 feet and has 23.5 inches of precipitation per year, with a December maximum of 2.58 inches. Because it is cloudier than Craig its annual range of mean monthly temperatures is 4 Fahrenheit degrees less (47 F°), only as much as is usual around Salt Lake City, though considerably more than at Boulder. Steamboat Springs is a ski and summer resort, with 160 inches of snowfall and a mean temperature of 14°F in January. Its mean temperature in July is only 60.6°F, though July afternoons average 81.4°.

In the picture, deciduous oak chaparral (which is said to have a strong serviceberry component throughout the Yampa and White River valleys)

Figure 42. The Steamboat Springs Basin

covers most of the base of the hills adjacent to the fields and is considered to prevail up to about 8,000 feet. The view shows, however, that it interfingers very extensively with upper montane vegetation. Conifers descend the shadow slopes along each stream course, and aspen descend with them to the margin of the flood plain, but both are much more extensive upslope. The pattern of chaparral and aspen is spotty, because both tend to grow in clumps.

In the distant south, the Park Range, seen to the left, dwindles to a hill-land on approaching the Gore Canyon of the Colorado, near which it meets a zone of hills lying east of the White River Plateau. The village of Yampa, 7,890 feet, in the headwater basin of the Yampa River near the base of the White River Plateau, has only 17 inches of precipitation per year in spite of its altitude, and has a definite July precipitation maximum because of the lee provided by the White River Plateau to the west.

X. Hills of the White River Watershed

Twenty to thirty miles south of, and roughly parallel to, the lower course of the Yampa River is the valley of the White River. That stream heads on the White River Plateau in Colorado, as do several Yampa tributaries, but drains directly west to the Green River in the Uinta Basin in Utah. It has no extensive plains but has many hills and small mountains.

Figure 43. An Arroyo in a terrace margin at 5,800 feet in the White River Valley north of Calamity Ridge, September 1968. Since settlement of the region, a tendency for small or intermittent streams to intrench themselves has been observed over much of the area of our southwestern states. Several explanations have been put forward, of which one is that increase in grazing pressure has reduced protective plant cover in a climate which is marginal for livestock raising. The many new gullies, called arroyos, could be a minor tactical obstacle of considerable importance. This one, in the floor of a partly stabilized older gully, is more clearly seen but less typical than that in Figure 44. The sagebrush and pinyon-juniper communities seen here are both important at lower montane levels in the White River region.

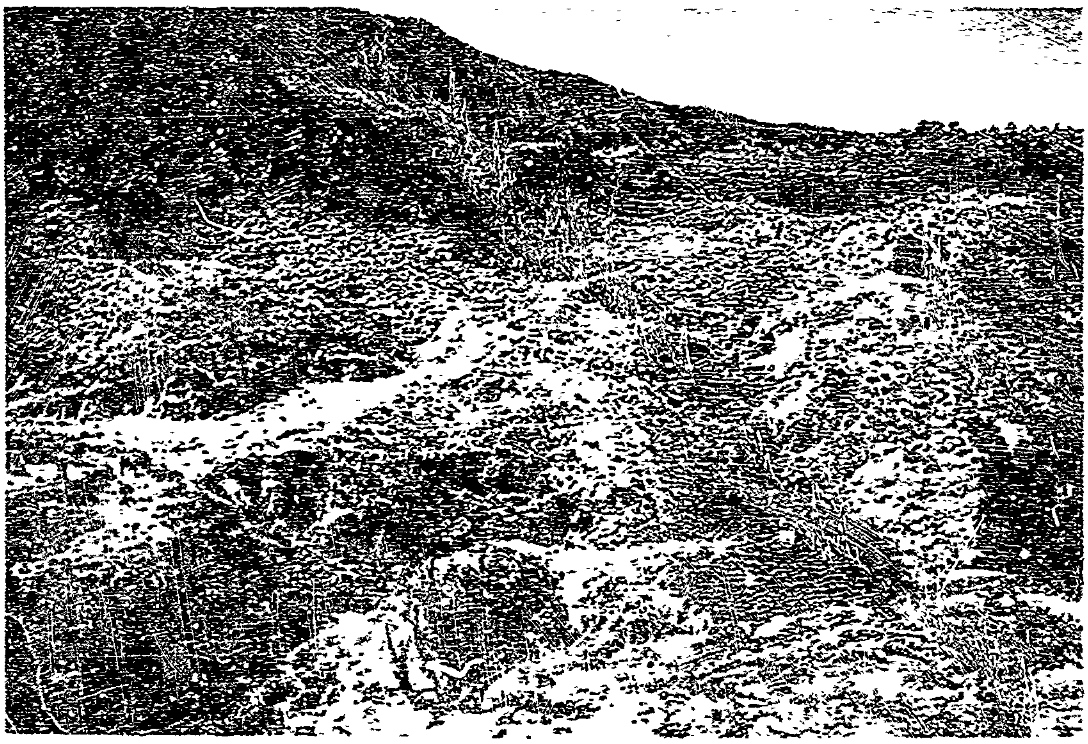


Figure 43. An arroyo

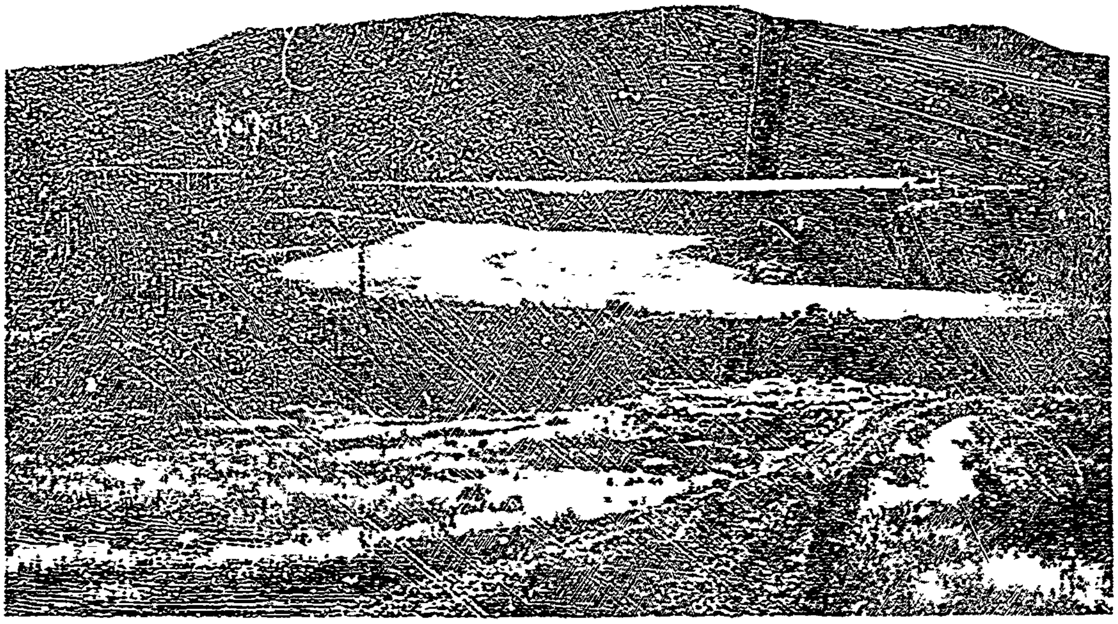


Figure 44. Hills southwest of Meeker

Figure 44. Hills Southwest of Meeker on Colorado Route 13, September 1968, about 7,000 feet. View west. Sheep Creek is seen in the near ground, intrenched in an arroyo roughly 20 feet deep, which separates trafficable and productive surface on opposite flanks of the north-south valley. The arroyo is continuous for several miles and effectively divides what would otherwise be a single tactical corridor. Chaparral of oak and serviceberry occupies much of the hill. The pinyon-juniper pattern seen here relates to outcrops on the hillsides.

Figure 45. Flag Valley, south of Meeker, September 1968, 8,000 to 8,700 feet. View south into the headwaters of Fourteen Mile Creek. At this level, semiarid lowland vegetation has largely dropped out of the picture. The vegetation is montane: aspen, deciduous oak chaparral, and some groves of conifers (fir or pine) on shade slopes. Wheat is not grown at this level. This area is heavily used as pasture for sheep. Slopes to the right ascend to the Grand Hogback (Fig. 46), those to the left (east) to the White River Plateau (Fig. 47).

Figure 46. The Grand Hogback at Meeker, September 1968. The water gap near Meeker, the town seen above and to the right of the farther wheat fields, is at 6,160 feet and the near crest of the hogback is at about 8,000 feet, rising southward toward the aircraft. Flag Valley is seen to

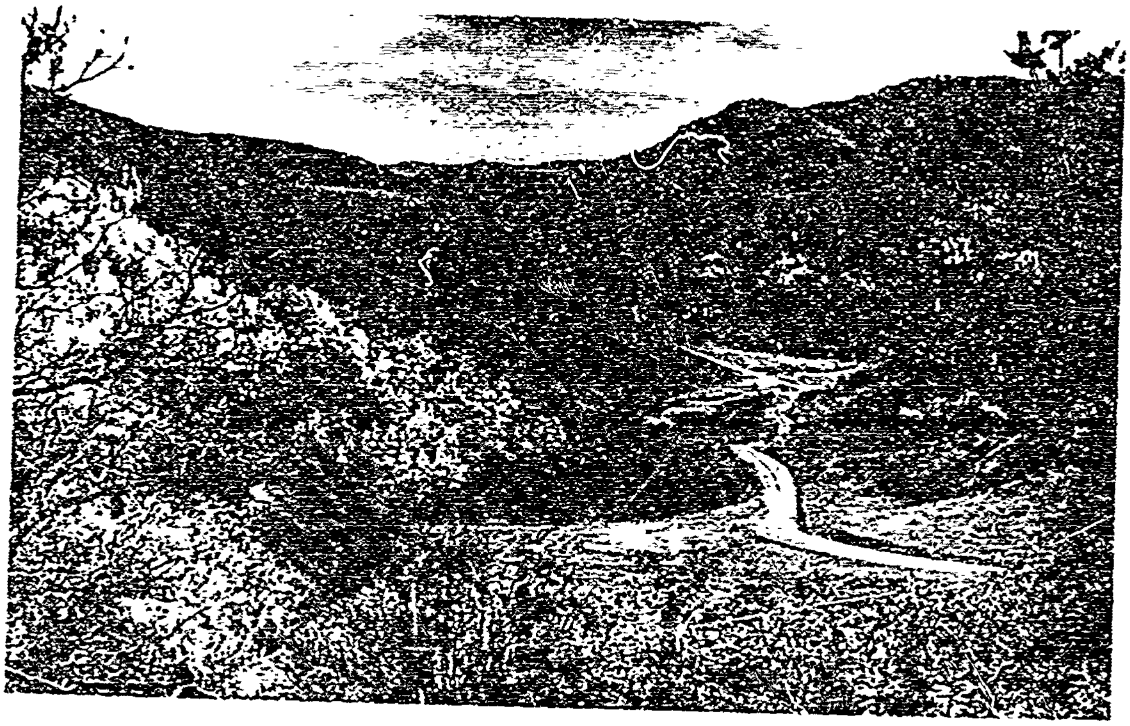


Figure 45. Flag Valley

Figure 46. The Grand Hogback

the right, several miles north of Figure 45 (down Flag Creek) at a level used for wheat and cattle raising. Sheep Creek (Fig. 44) is to the left of the hogback.

The strata seen in the hogback are the Cretaceous Williams Fork and Illes Formations, also seen in Figures 39 and 40. The vegetation is pinyon-juniper, oak-serviceberry chaparral, and some sagebrush. The tactical importance of such a barrier is evident, especially if we realize that the White River, which passes through it in the middle distance, is the main corridor through this country.

Meeker gets 16.8 inches of precipitation per year with a 2-inch April maximum. Its range of mean monthly temperatures is 45.5 Fahrenheit degrees, from 20.7°F to 66.2°. July afternoons average 86.1°F.

XI. The Park Ranges, A: The White River Plateau

The White River Plateau is a roughly circular area of partly undissected upland without sharp alpine summits. It is almost all within the southern margin of the study transect and is about 45 miles in diameter. Its southern and western part, some of which is seen here, is on Triasic and Permian strata and is largely upper montane or subalpine (9,000 to 11,000 feet). Its higher eastern and northeastern part is on Tertiary lava flows, which tilt upward above timberline (11,000 feet) in a number of places, reaching 12,493 feet on one of several summits in or near the study transect which are called Flattop Mountain. The term "flattops" is also used as a generic term for summits on the plateau.

The plateau upland has gentle slopes for the most part and has been occupied in the past by an icecap which left many lakes and moraines in its higher part. Its margins, on the whole, are abrupt. Formidable lava cliffs occur on its north and east flanks. Canyons and glacial gorges cut the rim in many places, so that undissected plateau is seldom as much as five miles across.

Figure 47. Aspen, Meadows, and Spruce-Fir Forest on the plateau southeast of Meeker, 10,000 feet, September 1968. The view is south

Figure 47. Aspen, meadows, and spruce-fir forest

toward Rifle, Colorado, above which the canyon streams which head here join the Colorado River. Among the aspen are groves of dead spruce, of which a great number throughout this region have been killed by bark beetles. Windfall of the dead spruce will be a serious obstacle to foot travel for many years. The subalpine meadow here is rich seasonal grazing. Because of heavy snow, the cattle are trucked back down to the lowlands for the winter, where forage crops to maintain them have been raised under irrigation.

Figure 48. Derby Peak, 12,184 feet, one of the White River Flattops, October 1964. View south. The lava beds seen here form the headwall of a cirque in which a glacier was formerly maintained by snow drifted from a broad alpine summit upland above. Such cirques form the heads of several canyons dissecting the White River Plateau. All the spruce in this view have been killed by bark beetles.

Military summary: See next section.

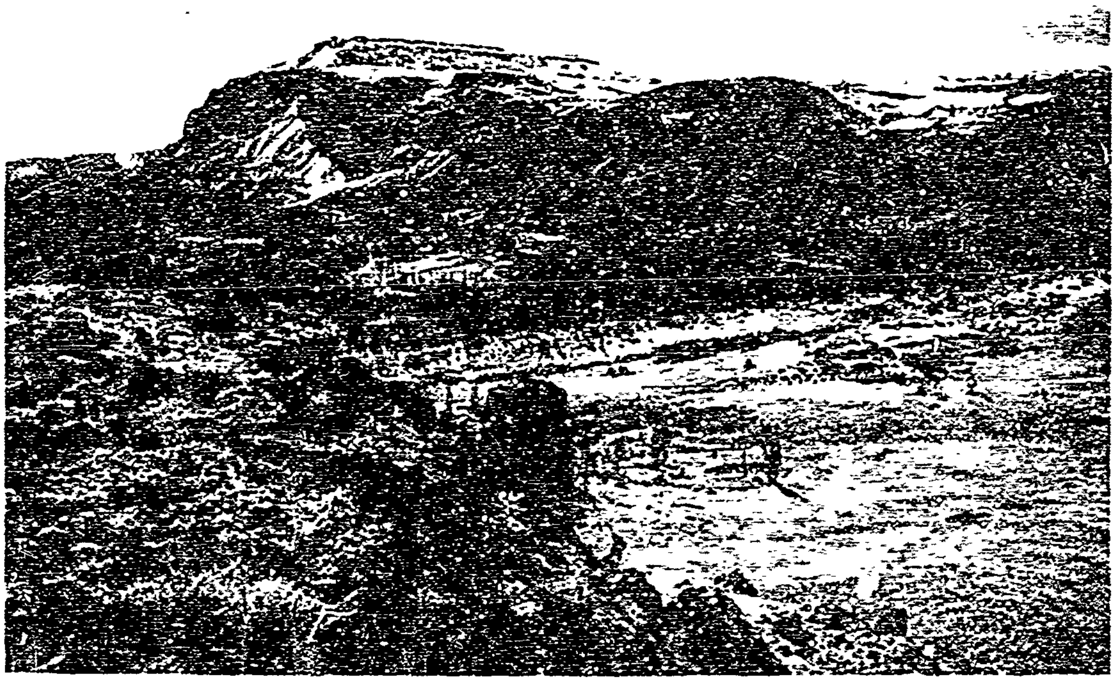


Figure 48. Derby Peak

XII. The Park Ranges, B: The Elkhead Range and The Park Range Proper

This is a mountain zone of varied height and ruggedness at the head of the Yampa watershed, encircling Steamboat Springs on the north and east and extending south with diminishing local relief to the Colorado River at Gore Canyon. Only at the northern margin of the transect does the Park Range rise above timberline (Mount Ethel, 11,940 feet). Like the Wasatch, the Park Range proper gets precipitation largely because of its north-south orientation rather than merely because of its height.

Figure 49. The Crest of the Elkhead Range, 11,045 feet, 20 miles north and somewhat east of Craig. This is a group of rough hilly uplands on Tertiary sediments surrounding resistant cores of late Tertiary intrusive rock. They do not quite reach timberline anywhere and have no summit plateau.

The interfingering of montane and subalpine vegetation seen here is largely due to radiation-cooled air flowing down mountainside drainage ways, which lowers their temperature, especially on clear r'ghts. Since they are moist as well as cool, such sites duplicate growing conditions which are normal on more open slopes at somewhat higher levels. Troops stationed in such sites might sometimes be uncomfortable at night even though their

Figure 49. The crest of the Elkhead Range

clothing and bedding would have been adequate at the same altitude on a slope or ridge.

As elsewhere in this region, subalpine forest is seen to have meadow openings at its higher levels. The pattern of aspen leaves in different stages of fall coloration here suggests genetic and age differences among several vegetative stocks of the species. Changes in the size and spacing of trunks, and in the amount of down timber, between one such aspen stand and the next can be expected to affect forest trafficability.

Figure 50. The Park Range and Route 40 at Rabbit Ears Pass, 9,426 feet, view east. This photograph should be compared with Figure 42, which covers some of the foreground as it is seen from the north beyond Steamboat Springs. In this view, the north end of Middle Park lies beyond the range in the center and to the right of the view. Valleys tributary to North Park originate to the left beyond the range.

The general level of the range crest here is about 10,000 feet. It is an incompletely dissected rolling subalpine upland like much of the

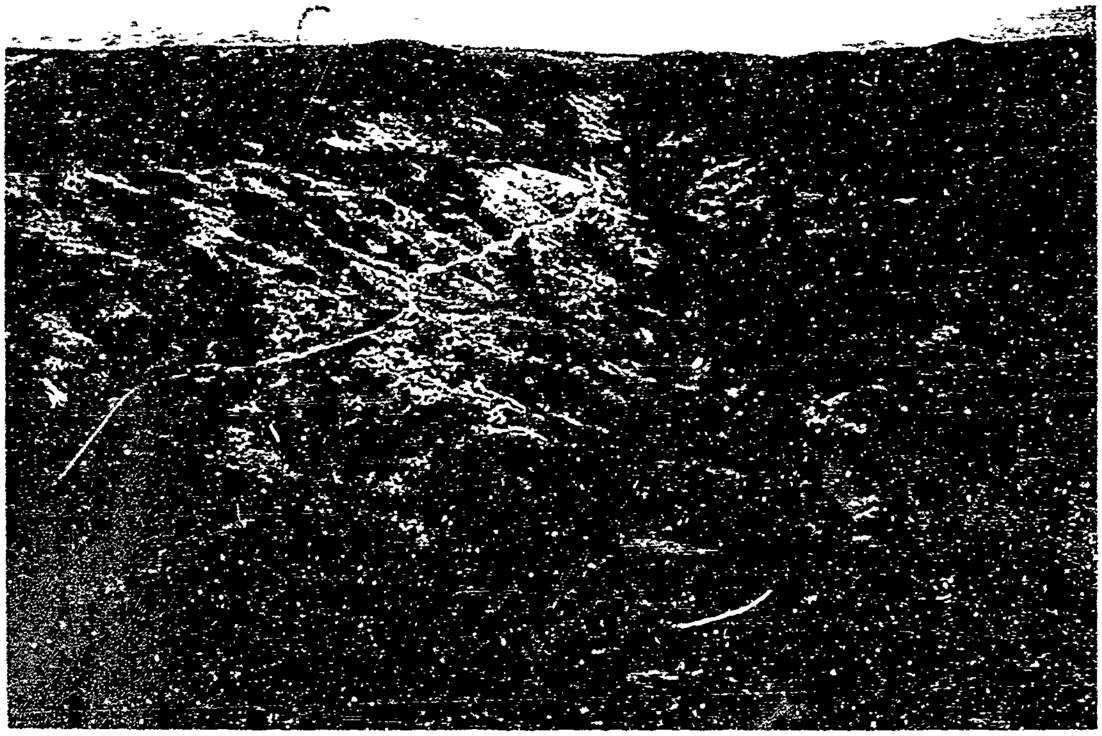


Figure 50. The Park Range and Route 40 at Rabbit Ears Pass

White River plateau but it is much more linear from north to south and has more nearly continuous forest. However, there are enough meadows on its crest to aid trafficability quite a bit. On the range flank, aspen and oak-serviceberry chaparral form interfingering upper and lower montaine vegetation zones. Lower slopes have been partly cleared for pasture.

Figure 51. The Big Creek Glacial Trough in the Park Range, October 1964. This view looks northeast toward a small Uinta-type alpine summit upland on The Dome, 11,600 feet, just south of the northern boundary of the study transect. The same upland continues to the right of this view (south) over the crest of Mount Ethel, 11,940 feet. Higher and somewhat more fully dissected alpine uplands lie to the north. Cirques in that area are large, with much rock glacier, and have floors which are less flat than those of the Uintas because glacial dissection has been deep.

Figure 51. The Big Creek glacial trough in the Park Range

John James and other investigators from the University of Colorado agree, on the basis of observation of aspens and other ground vegetation, that this part of the west slope of the Park Range gets relatively heavy precipitation. That conclusion is supported by the fact that subalpine forest is seen here to be relatively dense, and to occur on topography which indicates strong Pleistocene glacial erosion. Such observations are not surprising, since Pacific air must rise here to cross the range eastward, and should produce much winter snow. It seems reasonable, furthermore, that considerable amounts of Gulf air may enter the area in summer up the valley of the Colorado River from the southwest, producing thunderstorms at the season when moisture can best be used by vegetation. However, climatic data are lacking for the range.

Military summary: Park Ranges A and B. Alpine topography is lacking on the Elkhead Range and is quite limited within the boundaries of the transect on the White River Plateau and the Park Range proper. The Gore Range, to be discussed below, is considered a Park Range also, as are the Tenmile and Mosquito Ranges further south. The Gore is particularly alpine.

Except in the Elkhead Range, which has no summit plateau, uplands with moderate gradients occupy most of the subalpine zone in this part of the study transect. They are not more than a few miles across at any point but permit a degree of ground mobility near range summits which would greatly affect tactics. The White River Plateau has an intricate pattern of subalpine uplands and lies off the main routes. The Park Range proper, on the other hand, is a simple linear mass lying across Route 40.

Ground attack on the Park Range from either flank might advantageously be launched simultaneously from many points, since only the development of Route 40 and lesser roads has given some routes to its crest an advantage over others, and those routes could easily be blocked. Meadows on the range crest could be used as landing zones for airmobile forces if resistance in the range was expected to be of serious magnitude. The White River Plateau and Elkhead Range would be better refuge areas for irregular forces. Except on roads and trails, movement through lower montane chaparral is more difficult in each range than through aspen or coniferous forest above.

XIII. The Gore Range

Thrust upward along a fault on its southwest flank, the Gore Range is the most consistently rugged alpine range in northern Colorado, yet its granitic and crystalline metamorphic rocks are too badly shattered, and its summit altitudes are not quite high enough, to attract as many climbers as do the similarly rugged San Juan Needles in the southern Colorado Rockies. Like the Wasatch, the Gore is a narrow range within which military forces would have little room to maneuver. Only its northern part lies in the study transect.

Figure 52. The High Gore, June 1962

Figure 52. The High Gore, June 1962. A view southeast from over Mount Powell, (13,534 feet), which is not seen. The general level of the higher peaks, which are strikingly accordant when seen from the range flank, is about 13,000 feet. Timberline is approximately 11,000 feet. Oversnow movement on foot would not be difficult in these basins when the snow is stable, but in the general run even of Colorado weather avalanche hazard is considerably greater here than in the Wasatch. Furthermore, trafficable cols between basins are much less numerous and more difficult in the Gore.

Terrain of the sort seen here forms the crest of the Gore for 19 miles, of which

14 are without passes, or any cols much easier than those illustrated. There are no climatic records for the range, but snowfall is known to be exceptionally heavy for Colorado in the Vail resort area a few miles southwest. As in the Wasatch and Uintas, snow cover here is entirely seasonal. Glaciers are no longer present, and rock glaciers have occupied the sites of their last remnants.

Helicopter-supported troops could use explosives to tunnel into these crests and live there in any weather if there were occasion to do so, but their mobility on foot in winter would amount to little more than an occasional ski run to the valley.

Figure 53. The High Gore, October 1964. A view northeast across upper Piney Creek in the same area seen in Figure 52. Low crests (11,600 feet) to the left just beyond the 13,000-foot Gore are those of another set of Williams Fork Mountains. This set drains north (left) to the Colorado River near Kremmling in Middle Park, as does the northeast face of the Gore. The horizon of this view lies on the Colorado Front Range, with Longs Peak (14,255 feet) 56 miles away to the left of center, and the Arapaho peaks (13,506 feet) just to the right of center. Longs Peak stands well above the regional alpine summit accordance. The higher peaks in the rest of the Front Range have about the same altitude as the general

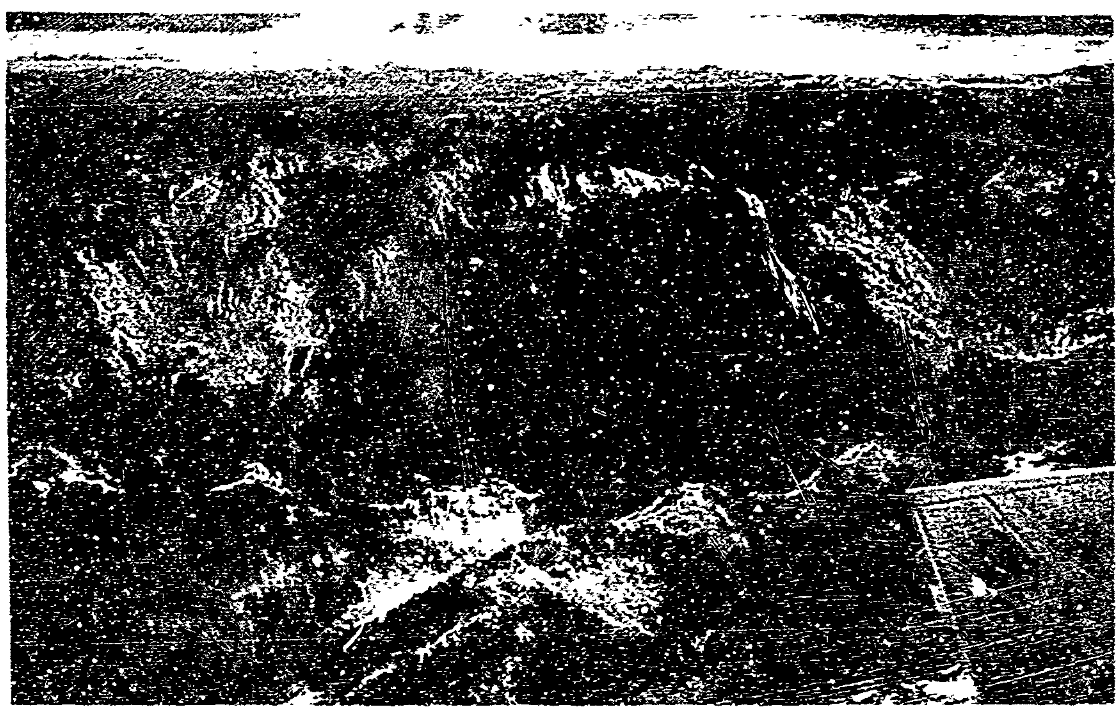


Figure 53. The High Gore, October 1964

run of Gore summits, but are less closely accordant. That is, they commonly stand several hundred feet above or below 13,000 feet.

The main valleys on either flank of the high Gore are at about 8,000 feet, so that local relief in the range is generally about 5,000 feet, and nowhere over 6,000 feet, unless it is calculated from the floor of the Gore Canyon of the Colorado, which lies at 6,800 feet 17 miles northwest of Mount Powell. The distinctive character of the range is thus due to its abruptness rather than to exceptional height.

The poor quality of the rock in this range, both from the sporting point of view and from that of troops who might have to train on it, is apparent in this view from the absence of massive cliff faces, the number and close spacing of couloirs, and the volume of talus which has been swept down them, largely by avalanches. Field experience further south in the range confirms its intense jointing at alpine levels. Erosion is rapid. The range remains rugged only because of its geologic youth.

Where possible, climbing in the higher parts of the Gore should be done along ridges, however rugged they may be, to permit disturbed rock to fall away to the side harmlessly. That requirement alone is enough to create defile problems even for units as small as a squad. If a steep rotten gully must be climbed by as many as two men, the second should either avoid climbing below the first or should follow the first so closely that a falling stone cannot build up strong momentum. Falling at full speed, loose rocks are, in effect, much like shell fragments, and similarly require exposed persons to lie prone, in defilade if possible. Helmets are valuable protection and in lightweight styles they are being used increasingly by sporting rock climbers even on firm rock.

Military comment: Gore Range. This range lay within easy reach of Camp Hale during World War II, and could have been used as a realistic, if risky, training area if the 10th Mountain Division had expected to fight in the higher Alps. However, though the fact was not widely acknowledged, the Division command was aware that offensive warfare in really rugged alpine mountains was not practicable at that time if resistance was on such a scale that a large number of troops were required. Furthermore, the Division was not authorized to risk many casualties from mountaineering hazards during training, nor were they equipped to evacuate them from terrain such as the Gore.

Though the Gore remains unpleasant terrain for training, many equally rugged ranges have better rock, and increasing aerial mobility is solving the other problems which the 10th Division would have encountered here. Mountain terrain in the trans-Eurasian frontier zone is not ordinarily as difficult for military operations as that of the Gore Range, and most mountains there must be less so, except where they rise considerably more than 2,000 feet above timberline. Many mountains in mid-Asia are indeed very large, but even airmobile warfare will presumably avoid the upper slopes of those ranges during the foreseeable future.

XIV. North and Middle Parks

On the east flank of the Park Ranges, their subalpine and upper montane forests descend to very high sagebrush basins. Such basins in the transect are all included under the terms North and Middle Parks. Montane forest surrounding the basins is said to be mostly lodgepole pine. Chaparral is lacking because of altitude. On the periphery of the Parks, sagebrush openings are believed to give way upvalley in many sites to subalpine meadow, and the bordering forest there may be spruce-fir rather than pine.

The part of North Park which lies in the transect is practically all above 8,000 feet, as is the southern part of Middle Park near Fraser. Near Granby and Kremmling, altitudes are below 8,000 feet along the Colorado River, but level surfaces on which fixed-wing aircraft might land in the Parks are extensive only at the higher level. Similar surfaces approach 10,000 feet in South Park south of the transect. They are thus as high as similar surfaces, also largely alluvial fans, between 9,000 and 10,000 feet in the strategically located Tsaidam Basin of northeastern Tibet. The Tsaidam region has little or no forest, at least partly because it has been occupied by grazing nomads for many centuries.

Figure 54. The Illinois River Alluvial Fan, North Park, lying at about 8,300 feet at the junction of the Illinois River with Deer Creek in the left foreground. View southwest, October 1964. Climatic data is available from Walden, 8,130 feet, about 10 miles downstream. Its mean annual precipitation is only 9.5 inches, so that sagebrush is seen on the crest of 8,942-foot Owl Ridge in the foreground. August is the least dry month, with 1.34 inches. Beyond the creekbank willows, usual at such levels in Colorado, fields are seen to be spotted with haystacks to feed cattle through the winter, which averages 15.3°F in January at Walden. July averages 44 Fahrenheit degrees warmer (59°F).

The distant high crest to the left is the Gore Range, 58 miles south. The Rabbit Ears Range is seen as forested crests in the middle distance. It reaches 11,819 feet to the left. Timberline follows its level crests closely, so that meadows (alp slopes) provide good routes along them.

Figure 55. Wolford Mountain from the Air, 9,230 feet, near Kremmling, Middle Park, April 1966, view east. Route 40 runs from left to right across the near ground. Muddy Creek, the main drainage to the Colorado from this part of Middle Park, runs parallel to it at 7,400 feet along the base of the hill. It meets the Colorado four miles to the right (south). The Colorado Front Range forms the skyline 40 miles away, with Longs Peak to the left of center. Notice the extent of badlands caused by geologically very recent intrenchment of the Colorado River, which acts here as a temporary base level of erosion.

Figure 54. The Illinois River alluvial fan, North Park

Figure 55. Wolford Mountain from the air

Figure 56. Wolford Mountain from Route 40, June 1962, view east. The lower limit of conifers in Middle Park, generally attributable to lack of precipitation and to fine-textured alluvial soils on which trees do not compete effectively with sagebrush for water, is seen also to correspond here to a thrust fault at which granitic rocks, producing relatively coarse soils, overlie sediments producing fine ones. The erect conifers are lodgepole pines. The prostrate ones are believed to be pinyon pine near its upper altitudinal limit.

The bare crests of the badland ridges which have developed in the sedimentary formation on either side of Muddy Creek are evidence of frost disturbance of ground consistently stripped of snow by winter winds. Sagebrush (or another desert scrub species) is seen to occupy only ground which is protected by snow during winter thaws. Snow can be inferred to be somewhat scant here, yet troops on foot without skis or snowshoes might have difficulty in drifted hollows.

Kremmling, 7,322 feet, four miles away on the Colorado, gets 10.6 inches of precipitation per year and 1.34 in August. Its monthly mean temperatures have a range of 49 Fahrenheit degrees, from 12.4° in January to 61.5° in July. July afternoons average a dry and comfortable 82°.

Figure 56. Wolford Mountain from Route 40

Figure 57. The Fraser-Granby Basin, Middle Park, October 1964, view northwest. The village of Fraser, 8,568 feet, which is often cited as a "cold hole" in Denver radio weather broadcasts, lies beside Route 40 and the D&RGW Railroad just off the left margin of the picture. The town of Granby, 7,935 feet, lies near the Colorado where that river is seen on the more distant basin floor to the left. The willow-grown stream among hayfields in the near right is Ranch Creek. Its junction with the Fraser River near the bend of the railroad is at about 8,400 feet.

Fraser actually has a winter climate no more severe than that of Kremmling, 1,000 feet lower, with a range of 42.5 Fahrenheit degrees between a mean January value of 12.5°F and an average of only 55°F in July. It gets 16.8 inches of precipitation per year and, being close to the Front Range, gets the equivalent of 1.9 inches in April, mostly as snow. A rainfall peak of 1.6 inches occurs in July. Grand Lake, 8,576 feet, on a lake up the valley to the north (right distance) has a very similar climate and, as a lakeshore resort, profits from the cool summers.

Timber in the foreground is spruce-fir on the Tertiary sediments of the North Park formation. Front Range granites and metamorphic rocks extend across the valley in the hills of the middle ground.

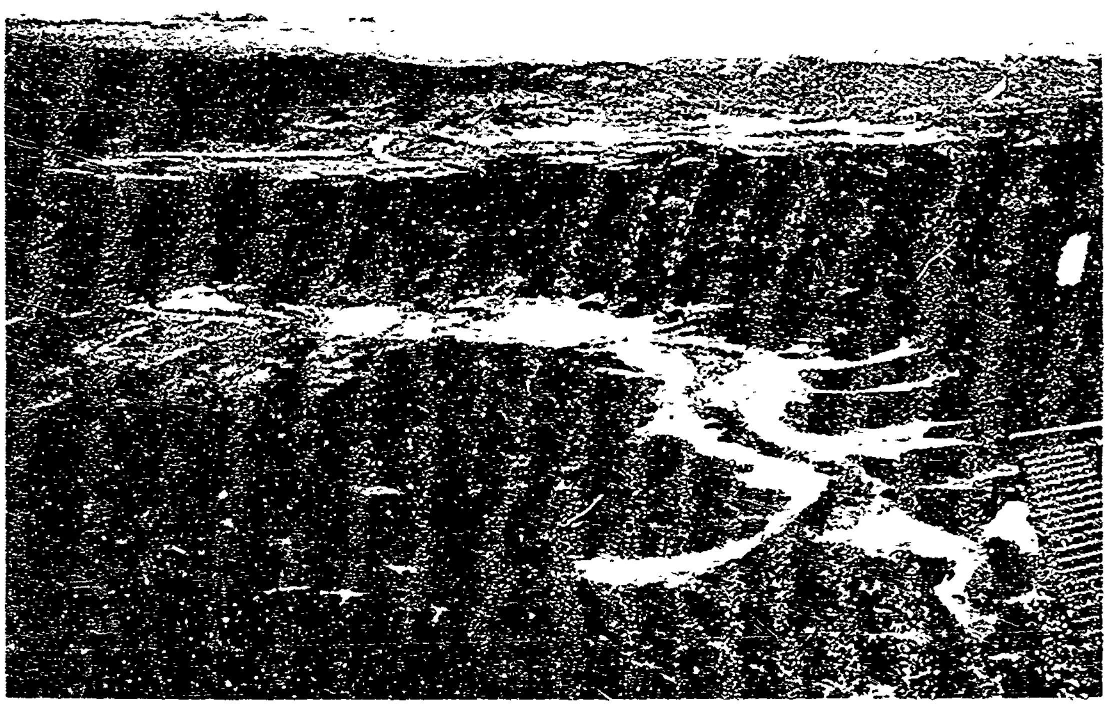


Figure 57. The Fraser-Granby Basin, Middle Park

Military comment: North and Middle Park. Terrain resembling the Rocky Mountain Parks in Colorado would be suitable for landing of large STOL fixed-wing aircraft such as are now available to major powers. Troops making a landing in such a basin would be involved immediately in the adjacent mountains, where passes would have to be occupied if the airhead were to be protected and properly exploited. Even at the highest levels in the transect and currently to as much as 16,000 feet in higher ranges, small units could be deployed and supported by helicopter. Because payloads at such altitudes are still small, helicopter operation would presumably be from a truckhead, or a fixed-wing landing site, as close to flight objectives as possible.

XV. The Colorado Front Range, A: West Slope and Crest

As on the west slope of the Wasatch and the corresponding slope of the Park Range near Steamboat Springs, precipitation appears to be relatively heavy in season on the west slope of the Front Range. Whether it exceeds that of the Wasatch is hard to say, since climatic data are not available at upper subalpine levels on the west slope.

Wherever we have data the snowy season in the Front Range is spring, with precipitation maxima in April or May. Snow blown off the range crest feeds the last small glaciers in the southern Rockies just east of its higher summits, but most of the east slope has less snow than the west flank.

Figure 58. The Glacial Trough of Cascade Creek, Arapaho-Navajo Summit Area of the Front Range, June 1962. This valley is typical of many of the west slope of the Front Range. Timber reaches 11,260 feet in this view but only where avalanches and heavy creeping snow are not a major factor. In the valley its margins descend almost to 9,000 feet.

The weight of Pleistocene glaciation here and on the Aropaho peaks to the right of this view up Cascade Creek, relative to that near Berthoud

Figure 58. The glacial trough of Cascade Creek, Arapaho Peaks, Front Range

Pass, suggests that precipitation here could easily be 20 inches more per year than at that relatively sheltered site, and may thus be at least comparable to over 55 inches near timberline in the Wasatch.

Figure 59. Less Glaciated Slopes, seen to the northwest from 12,400 feet near Arapaho Pass, July 1962. Granby Reservoir, 8,280 feet, is 8 miles downvalley. Timberline is higher on the sunny slope here than in Figure 58, since Santanta Peak in the middle ground is 11,979 feet. Vigorous ice has undercut its right side but not its left flank. Ridges having continuous crests barely above timberline, like this one, are very common not only in Colorado but throughout our western ranges. The weathered-down slopes just above the treeline are alp slopes, and are generally much more trafficable than nearby slopes above and below. For example, fine soil gives way to less trafficable felsenmeer upslope in the foreground, as it often does with increasing altitude in the Rockies.

Figure 60. Berthoud Pass and the Moffat Tunnel Sector of the Front Range, view south, April 1966. The Moffat Tunnel of the D&RGW Railroad passes under the continental divide about three miles south of the camera position in this view. It begins at South Boulder Creek, seen on the left of the view as a forested bowl under the eastern spurs of James Peak (13,294 feet) and ends near Winter Park, the ski resort on the right

Figure 59. Less glaciated slopes

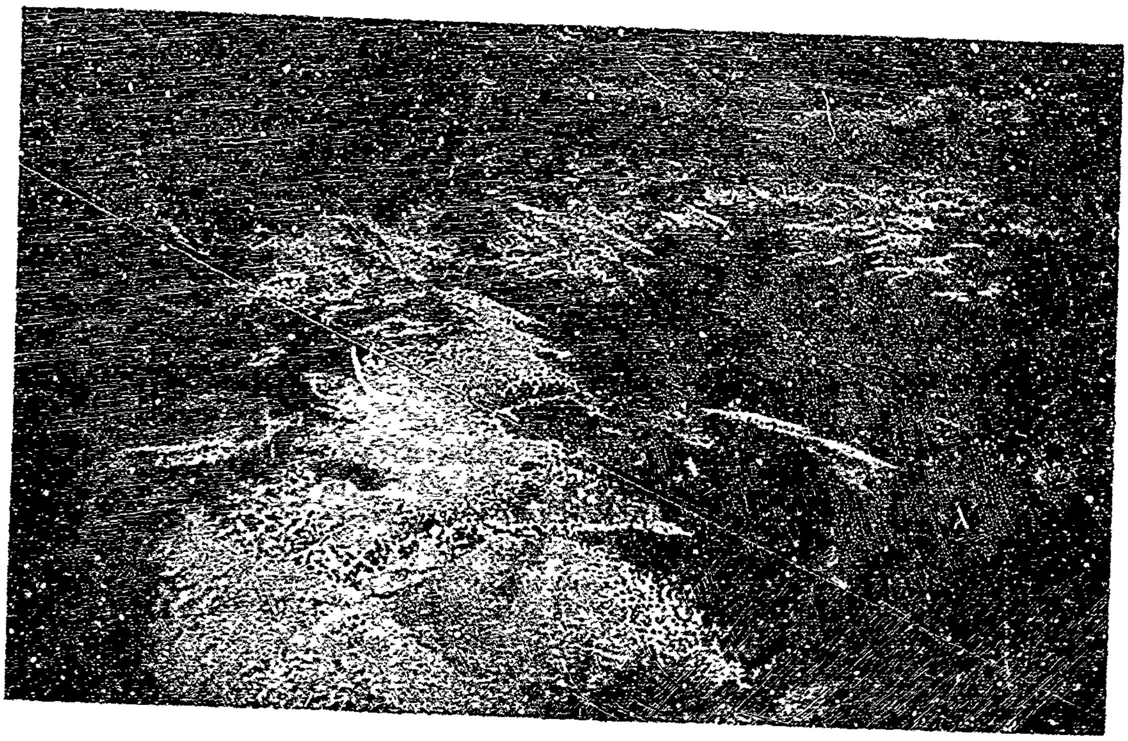


Figure 60. Berthoud Pass and the Moffat Tunnel sector of the Front Range

margin of the picture. Route 40 runs south up the Fraser River between James Peak and Winter Park to Berthoud Pass (11,314 feet) and then descends Clear Creek to Denver, joining Interstate 70 on the way. Berthoud Pass is 14 miles away in this view. Clear Creek is a forested gorge beyond James Peak, seen descending to the east (left) on this side of 14,264-foot Mt. Evans, scene of recent Army high-altitude physiological research. Mt. Evans is 25 miles away on the left skyline, just south of the study transect. Notice that in spite of its height it has little snow because of its lee position relative to the range.

Loveland Pass, 11,992 feet, is another important all-weather pass which lies among the high peaks (including Grey's Peak, 14,270 feet) which are seen beyond Berthoud in this view. For 45 miles on this side (north) of Berthoud Pass there is no highway across the range. In Rocky Mountain National Park the Trail Ridge road, open only seasonally, climbs to 12,183 feet before descending to Milner Pass at 10,759 feet.

The near part of the continental divide in this view is at about 11,800 feet, with timberline between 11,000 and 11,400 feet. Westerly winds are seen to have stripped snow from the crest of the divide in this view. The resulting drifts have maintained glaciers in the past in cirques to leeward, and still maintain small ones east of higher summits to the north.

The base of the Winter Park ski runs is near 9,200 feet, and their top is near 10,500 feet.

Berthoud Pass gets 34.8 inches of precipitation per year at 11,315 feet, of which 4.15 inches fall in April and 3.47 in December, whereas stations on the east slope of the Front Range have their secondary maxima in summer. Its range of mean monthly temperatures is only 40 Fahrenheit degrees, since it has excellent air drainage. Its January mean is 11°F and July averages 51°F. In accord with the latter figure is its position less than 500 feet below a thermal timberline. The Winter Park precipitation gauge at 9,058 feet gets 27.3 inches of precipitation per year, of which 7.24 inches fall in March and 6.82 in January.

Figure 61. The Flattop Summit Upland, Rocky Mountain National Park, October 1964, view north to the Mummy Range. Mount Alice, 13,310 feet, is the broad felsenmeer ramp toward which the aircraft wing is pointed.

Though in the past the fact has not always been evident to students to whom an aerial viewpoint was not available, this view confirms the argument of other investigators that such uplands have been greatly modified by frost processes since they were last leveled by stream erosion, if they ever were. Such leveling would necessarily greatly predate glaciation,

Figure 61. The Flattop summit upland

yet two Pleistocene glacial cirques here at the base of the Mount Alice slope, as well as many other cirque headwalls and alpine glacial trough margins in this view, have been vigorously weathered by post-glacial frost processes which are causing them to merge again with surrounding uplands. The rest of the alpine uplands, on some parts of which glacial erosion may never have acted, have long been actively downwasted by the same processes.

Pedimentation contemporary with that of the Gilbert Peak surface in the Uintas may have been completed during the Tertiary close to these crests, and we know that subsummit gradation apparently equivalent to the Bear Mountain pedimentation occurred later in the Tertiary on the east face of the range. Those developments predated all glacial erosion here. Since then this has become an even more dynamic geomorphic situation in which Pleistocene and recent climate are strongly expressed. From the military point of view it is important that climatic stresses which might affect personnel are so evident in the landscape, since other climatic data from such sites are rare.

For the most part, trafficability on these uplands corresponds to that in the Uintas, since felsenmeer is similarly widespread. Glacial dissection of this range is deeper, however, and glacial trough walls and cirque headwalls are higher and steeper. There is no pediment west of the range here unless Middle Park and its tributary valleys are considered a pediment not yet very deeply dissected by the current headward progress of intrenchment up the Colorado River system (Fig. 55).

The climatic record which comes closest to representing this upland is that of the Army-sponsored Arctic and Alpine Institute station established in 1952 at 12,300 feet on Niwot Ridge on the east slope of the range further south (Fig. 66). It supports the argument that vigorous development in this view of graded felsenmeer surfaces and of solifluction patterns like those illustrated on the Uintas implies Arctic temperatures and permafrost. The magnitude of snow drift from such surfaces now and during the Ice Ages suggests that the effect of low temperatures here is reinforced by that of violent winds. Winter occupation of such terrain is quite possible with adequate preparation, and people can move around on it in good winter weather, as they sometimes do on similar terrain on Mount Washington in New Hampshire, but the need to do so should be carefully considered before military personnel are stationed on such uplands at that season.

Figure 62. A View South from North of the Arapaho Peaks, October 1964. Southward from the area of Figure 61 toward the Arapaho Peaks, the Flattop summit upland is increasingly interrupted by glacial cirques and troughs. Felsenmeer upland is therefore of small extent on the continental divide between Paiute Peak, 13,088 feet, the first sharp crest on the left margin of this picture, and Arapaho Peak, 13,502, five miles south.

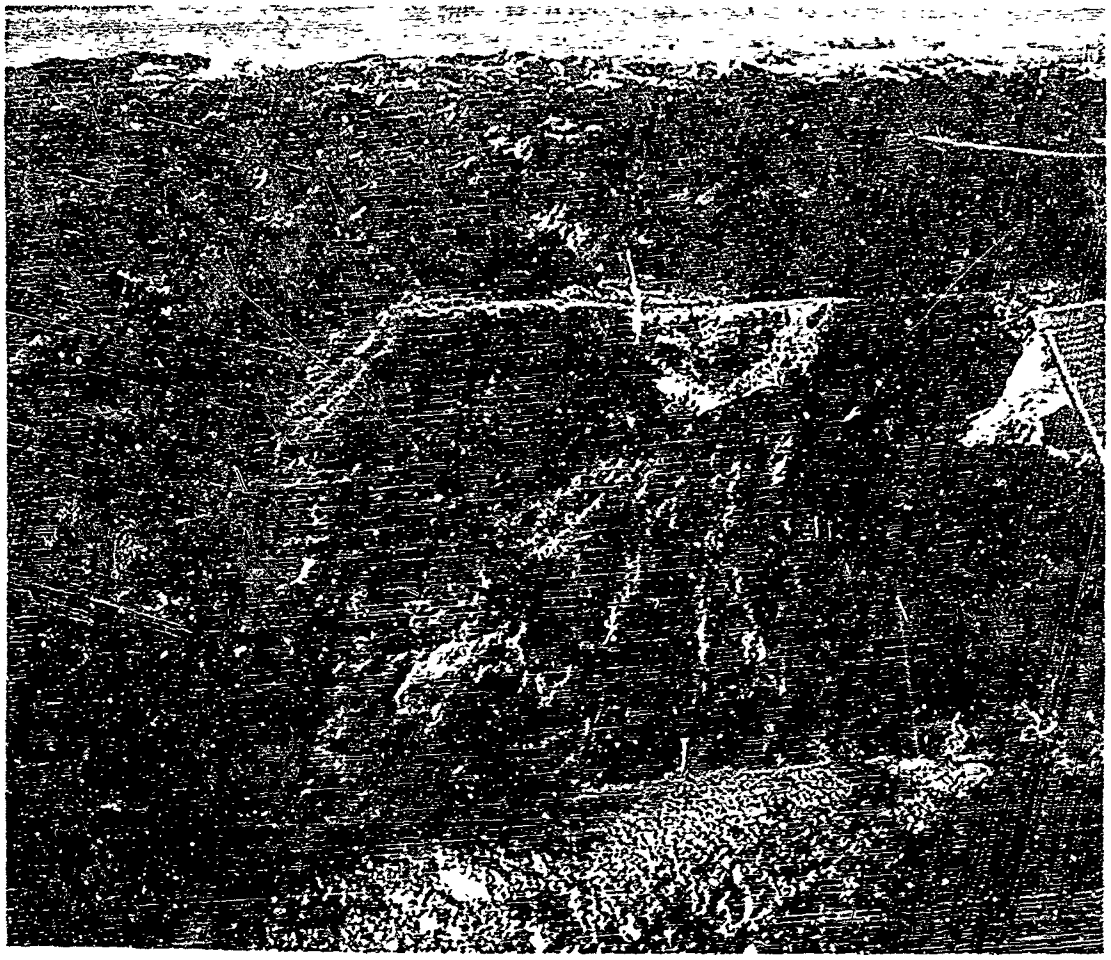


Figure 62. A view south from north of the Arapaho Peak

In the lee of Arapaho Peak lies the largest remaining true glacier in the southern Rockies. It was only 64 acres in extent in 1964. From its moraines, and from talus, massive rock glaciers have developed there. Beyond the Arapaho peaks the range crest drops to the levels seen in Figure 60, and lies increasingly in the shelter of the Vasquez Mountains to the west, so that ice was not massive on it even at the climax of the Ice Ages, and was always confined to the lee of the ridge. On the other hand, because precipitation was (and is) heavier there, Pleistocene ice was heavy on the windward side of the divide throughout the middle ground of this view.

The angle of the light in the near part of this view, plus new snow among the boulders of the felsenmeer and talus surfaces there, picks out

their texture very clearly and indicates what trafficability would be like there, provided we realize what the scale is. The nearest peak (Copeland Mountain) is 13,176 feet high; the Elk Tooth beyond is 12,848 feet; and the margin of the incompletely dissected felsenmeer upland beyond it is at about 12,750 feet, whereas St. Vrain Creek to the left descends to 10,700 feet in the shadows near the left margin of the view. The headwalls facing it are a thousand feet high over much of their extent. Rock glacier is extensive at their bases but is shadowed in this view.

Climbing the cliffs seen here would not be difficult if the route were well chosen, but military personnel would have to have suitable training before such routes could be of much tactical importance. Indeed, they should have considerable orientation before being placed in such an environment even by helicopter unless they are supposed to stay in fixed positions with good shelter and ample supplies.

Figure 63. The east face of Longs Peak

Figure 63. The East Face of Longs Peak, 14,255 feet, June 1962. The nearer lake, called the Peacock Pool by the National Park Service, is at 11,300 feet. Chasm Lake, snowcovered below the cirque headwall, is at 11,780 feet. The steep face of the mountain, which has become an exercise ground for advanced technical rock climbers in recent years, rises about 1,800 feet above the small Mills Glacier at its base. However, the summit is more readily reached over moderately steep slopes either from the north

or the south. The East Face is the alpine climax of the Colorado Rockies and is not tactical terrain in any ordinary sense, but troops could be placed by helicopter on almost any other part of the mountain if necessary, and would be reasonably mobile if they had had training approximating that of the best-trained units of the 10th Division in World War II.

Figure 64. Mount Meeker and Longs Peak, 13,911 and 14,255 feet, view west. This face of Mount Meeker was presumably once a cirque headwall but is now greatly weathered. It descends to Cabin Creek basin at the rate of about 2,500 feet per mile. Though this wall is boulder-covered everywhere, solifluction and avalanche erosion appear to disturb the felsenmeer a great deal. Varied tones in the photograph suggest that the rock is not altogether without lichen cover, yet the face is not recommended for traverse except with care and consideration. Each spring thaw will make it especially unstable.

Military comment: Front Range west face and crest. From the 8,400-foot level, almost 6,000 feet below the summit of Longs Peak and 4 1/2 miles southeast of its crest, North St. Vrain Creek has a moderate

Figure 64. Mount Meeker and Longs Peak

downslope gradient and takes 15 miles to descend the next 3,000 feet to the plain. Therefore, even the Longs Peak massif in the Front Range cannot be considered to have as much as 6,000 feet of local relief as compared with 6,750 feet or more for Timpanogos in the Wasatch, which is 2,500 feet lower. However, the absolute altitude and climatic severity of the Front Range are also military considerations.

Although the Front Range crest as a whole is a thousand feet or more lower than Longs Peak, its lack of low passes and the steepness of many of its glacial headwalls and trough walls, would make it a military obstacle not to be dismissed lightly. At 13,000 feet it is quite high for large-scale helicopter airlift at present, though not out of reach.

As in the case of other ranges in the study transect, defense of the Front Range crest would be worth the effort only if the defenders were not overpassed by airmobile forces sufficient to achieve the objectives of the attacker. Command of the air would prevent that possibility. So would strong occupation of all areas beyond the range which might become objectives. That might require more resources than were available, however.

XVI. The Front Range, B: East Face

Consideration of the east flank of the Front Range will be begun by discussing a sweeping view of it:

Figure 65. The Colorado Front Range and its Eastern Pediment, view from the south April 1966. Eastward of the Front Range crest in the study transect, its rugged topography generally does not extend below about 11,000 feet. The topographic break at that level is roughly approximated by a timberline which averages about 11,200 feet. The east face of the rugged crest has less snow cover in spring views than the windward face does, and its glacial trough walls and cirque headwalls have been more deeply riven by frost and thus stand somewhat less steeply in general than those on the west face of the Arapaho peaks, for example.

From the eastern edge of the rugged peaks a broad ramp surface cut in granitic and metamorphic bedrock descends 15 or 20 miles eastward to the plains margin, which is generally a few hundred feet below the 6,000-foot contour. The descent thus averages between 250 and 350 feet per mile. On the basis of Bradley's studies in the Uintas, authoritative opinion has accepted such ramps throughout the Rockies as pediments, formed in Tertiary time under arid or semi-arid conditions.

Figure 65. The Colorado Front Range and its eastern pediment

The Tertiary surface of which the pediment was a part was originally continued eastward at diminishing gradients, but without any break in slope, as depositional plains which are still represented by little-dissected areas (stream divides on the Great Plains) more than 20 miles east of the pediment foot. Nearer the Front Range, on the other hand, mountain-derived streams invigorated by Pleistocene climate have interrupted that surface by carving out a broad lowland in the soft Tertiary deposits, within which lie Denver, Boulder, and other cities.

Glacial action and increased stream vigor in Pleistocene time have also dissected somewhat the resistant rocks of the pediment, which are an eastward continuation of the rock of the range crest. On the upper part of the pediment, many valleys have the form of glacial troughs which descend eastward from the rugged crest. On its lower part many valleys become canyons of small or moderate size. Within an intermediate altitudinal zone from 7,000 to 9,000 feet, few glacial troughs or canyons have much depth, and local relief on the pediment is hilly in general rather than even moderately mountainous.

Along the plains margin, seen in the distance to the right here, sediments of late Paleozoic and Mesozoic age appear as outcrops dipping steeply east, so that they descend in that direction beneath less resistant Tertiary strata, and lie toward the west against the margin of the uplifted crystalline basement rocks which form the Front Range. The hogbacks formed by those sedimentary strata culminate near Boulder in "flatirons" more than 2,500 feet above the plain, but they are less high elsewhere.

The dark coniferous forest near timberline in this view, continuous on sunny and shady slopes alike, is subalpine spruce-fir with some stands of lodgepole pine. John Marr of the Arctic and Alpine Institute of the University of Colorado places the subalpine vegetation zone between 9,300 and 11,000 feet. Above and below it he designates 400 and 300 foot zones as transitional to alpine and montane vegetation.

The montane zone extends from 9,000 feet down to the plains. Its forest is seen here to be relatively dense on shadow slopes but sparse on sunny ones. It is often divided into upper and lower zones. Ponderosa pine is especially dominant below. Douglas fir is more prevalent above, particularly on shady slopes.

Much of the apparent open ground in this view at upper montane and lower subalpine levels on the pediment is seasonally leafless aspen. In this area aspen is a successional species which is eventually overgrown by the conifers cited above unless disturbance recurs. Lodgepole pine is also an important successional species in the upper montane and subalpine zones. Its prevalence in a given area of former burn or logging here has depended on the success of particular seed years. If lodgepole seed fails, disturbed areas may become meadow, which excludes pine but later gives way

to the vegetative spread of aspen. Where seeding has been successful, young lodgepole pine sometimes grows so densely as to be practically impenetrable on foot, and is thus a factor in military trafficability. Logging to supply mines and the lowland has been very extensive in the past. In this view practically all the montane forest and much of the subalpine forest is second growth.

The next view will be of Niwot Ridge, site of many climatic, biological, and other studies by the Arctic and Alpine Research Institute. In this view Niwot is seen as a long eastward projection of the alpine zone below the level of the rugged peaks.

Figure 66. The Alpine Zone, Niwot Ridge, view west, April 1966. The Arapaho peaks rise beyond Niwot. Spring is the snow season on the Front Range, yet broad areas of Niwot Ridge are seen here to have been swept free of snow. Such surfaces are never deeply snow-covered, and must be considered to retain for plant use much less than the total precipitation which might be measured on them by an accurate meteorological gauge. However, no precipitation gauge is accurate in such windy sites, particularly where much of the moisture falls as snow.

Figure 66. The alpine zone, Niwot Ridge

The foreground has alpine vegetation (tundra) on soils which include much silt but are stony (Fig. 68). Upslope along the ridge, boulders become more and more prominent until they form an open-jointed mantle several feet deep (a felsenmeer) over the stony silts. Under the silt layer, bedrock is subject to constant weathering, and its higher-standing riven fragments have been carried downslope for thousands of years as part of the creeping soil. The smoothed and largely felsenmeer-covered alpine surfaces which result are a field and photointerpretive indicator of severe frost climate.

The highest Institute station on this ridge is at 12,300 feet, not far from the junction of the broad ridge with the sharp peaks. It has recorded 25.2 inches of precipitation per year and would probably have an April maximum of precipitation except that in high winds snow is harder to catch in a gauge than rain. Three inches is the mean amount of precipitation recorded there in August. The April record averages 2.58 inches.

The January mean temperature of the Niwot station is 9°F, and that in July is 47°, the difference being only 38 Fahrenheit degrees. That should be compared with a difference of 25 F degrees between mid-summer and mid-winter means near the cloudy Cascade timberline, however. July afternoons average 54°F. The mean soil temperature there is below freezing: 30°F. Wind at the station has averaged 18 mph year round and 26 mph in December.

A feature of this view is the close association seen in the foreground between snowfield margins and scrub conifers (krummholz). Excess snow cover around tree bases would delay their growing season, which is minimal at this level in any case. On the other hand, the trees apparently cannot live without some extra moisture, and partial protection from winter wind, both of which are provided by the snow where it is not too deep.

The environment here is not so rigorous that observers have been unable to attend the high station. Movement to it in winter has ordinarily been by snowmobile most of the way, as much for the sake of the protection offered by the vehicle body as for speed, which is slow where felsenmeer must be crossed. Under favorable conditions the vehicles have generally been left at the end of the fine soils, and the felsenmeer has been traversed on foot.

The lake in the glacial trough to the left (North Boulder Creek) is one of a number of lakes from which Boulder, Colorado, draws much of its water. Silver Lake, 10,200 feet, the lowest lake, averages 28.2 inches of precipitation per year but has recorded 76 inches of snow in 24 hours during a spring snowstorm. One can guess that much of that amount was blown from Niwot Ridge.

Figure 67. Timberline and the Surface Texture of Drifted Snow on Niwot Ridge, April 1964, view southeast. Silver Lake lies in the valley

Figure 67. Timberline and the surface texture of drifted snow on Niwot Ridge

beyond the near crest, somewhat to the left in this view. The pattern of the snow seen here is that known as sastrugi, familiar in accounts of antarctic exploration. The wind-hardened ridges seen here are no more than 5 or 6 inches high, but they would interfere with downhill running by any but a skilled and very strong skier. However, the surface is firm underfoot, so that neither skis or snowshoes would be required here at this particular time.

The bulk of the foliage of the krummholz in this view is still covered by snow. Since the needles of conifers are capable of transpiring moisture in winter whenever the air is warm or radiation is sufficiently strong, and since their roots are frozen at this season so that the moisture cannot be replaced, the exposed foliage of trees near timberline is often killed by drying in winter (winter kill, a phenomenon familiar to horticulturists).

Timberline conifers, therefore, often have many dead limbs, and krummholz is characteristically closely sheared to the form of its protecting snowdrifts, as if the wind had actually cut it down to that level.

It is often possible by that means to determine in summer the usual depth of winter snow in timberline situations.

Krummholz is commonly much too dense to walk through but not quite dense enough to walk over except when it is drifted full of snow. It is thus a trafficability problem in many localities, but would also be excellent concealment. Individual bushes and broader fields of krummholz are seen to be several feet high here in summer, with winter-killed or young and vulnerable leaders rising to 6 or 8 feet.

Figure 68. Alpine Tundra, Niwot Ridge, April 1964, view west. This view, taken on the same day as Figure 67, shows the texture of the foreground of Figure 66, which resembles that of certain kinds of arctic tundra. The fences were erected to mark areas studied by Institute biologists and to keep stray cattle off the tundra.

Figure 69. Montane Forest near Sugarloaf Mountain on the Front Range Pediment, April 1964. The view is west (upslope) from the 8,500-foot level. Alpine crests near the 12,000- and 13,000-foot level are seen to the center and left on the skyline. Species seen in the foreground are

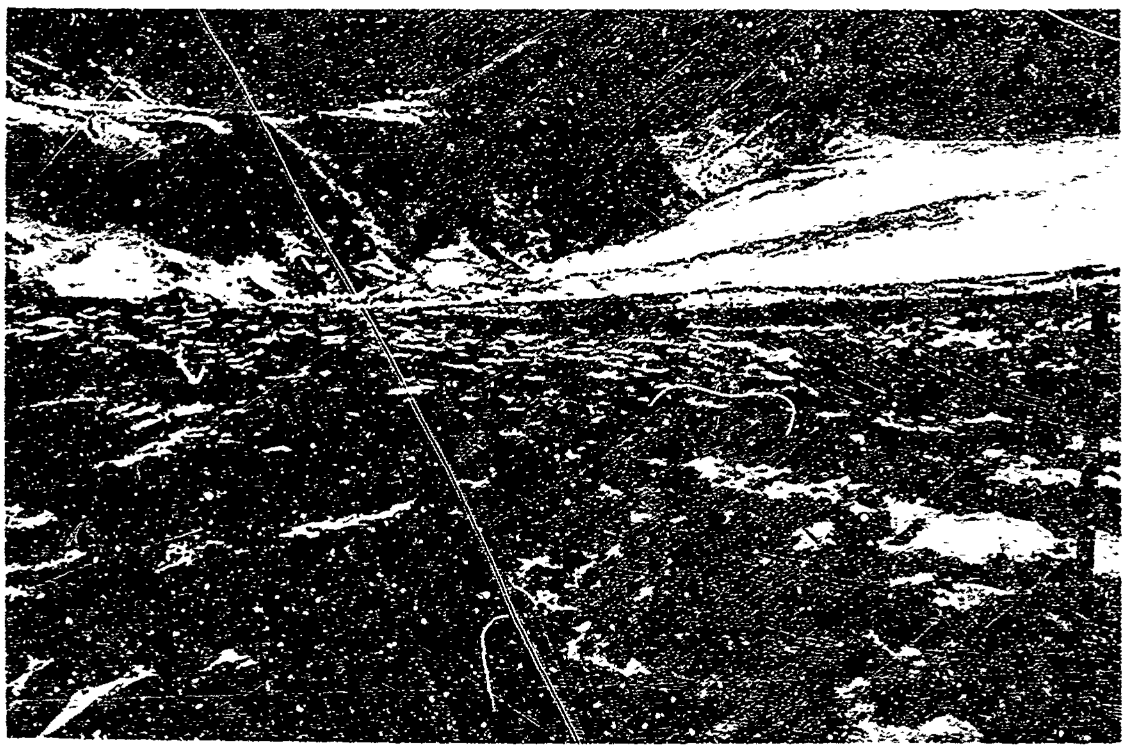


Figure 68. Alpine tundra, Niwot Ridge

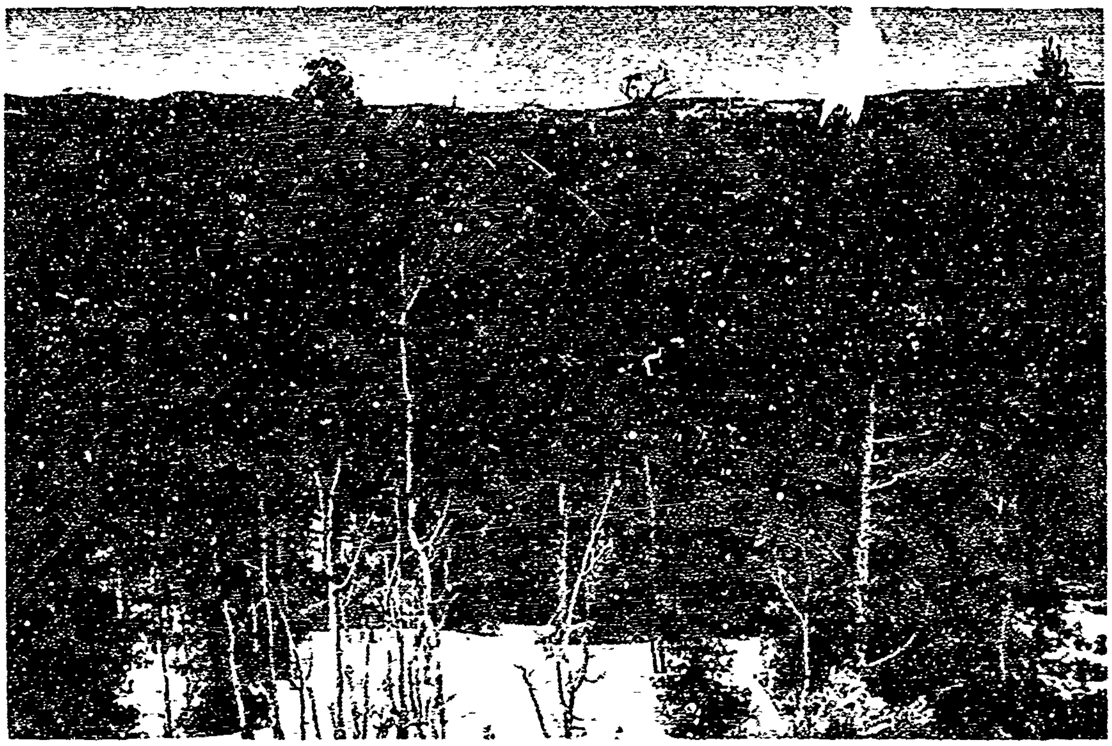


Figure 69. Montane forest near Sugarloaf Mountain on the Front Range pediment

aspen, lodgepole pine, Ponderosa, and Douglas fir. The low density of timber observed on sunny montane slopes in Figure 65 is seen again here on the far side of the valley of Four Mile Creek.

This view was taken not far from another of the climatic stations of the Arctic and Alpine Research Institute, located on the 8,500-foot contour. It gets 21.2 inches of precipitation per year, of which 3.24 fall in May. A secondary maximum of 2.41 inches falls in July, whereas December and January get slightly less than an inch. January mean temperature at this level is 22°F and that in July is 64°, the difference being 42 F°.

Figure 70. The Edge of the Plains North of Boulder, Colorado. View north, April 1966. These hogbacks mark the upturn and emergence at the mountain front of Mesozoic strata which underlie Tertiary formations and overlie ancient basement rocks across the breadth of the Great Plains. The granites and metamorphics of the range, which are a continuation of the Plains region basement, crop out a short distance to the left (west, upslope). Conifers seen here are Ponderosa pine. Open ground is covered by the short grass steppe vegetation characteristic of the Great Plains. As in other views in this series, the lower border of the forest seems

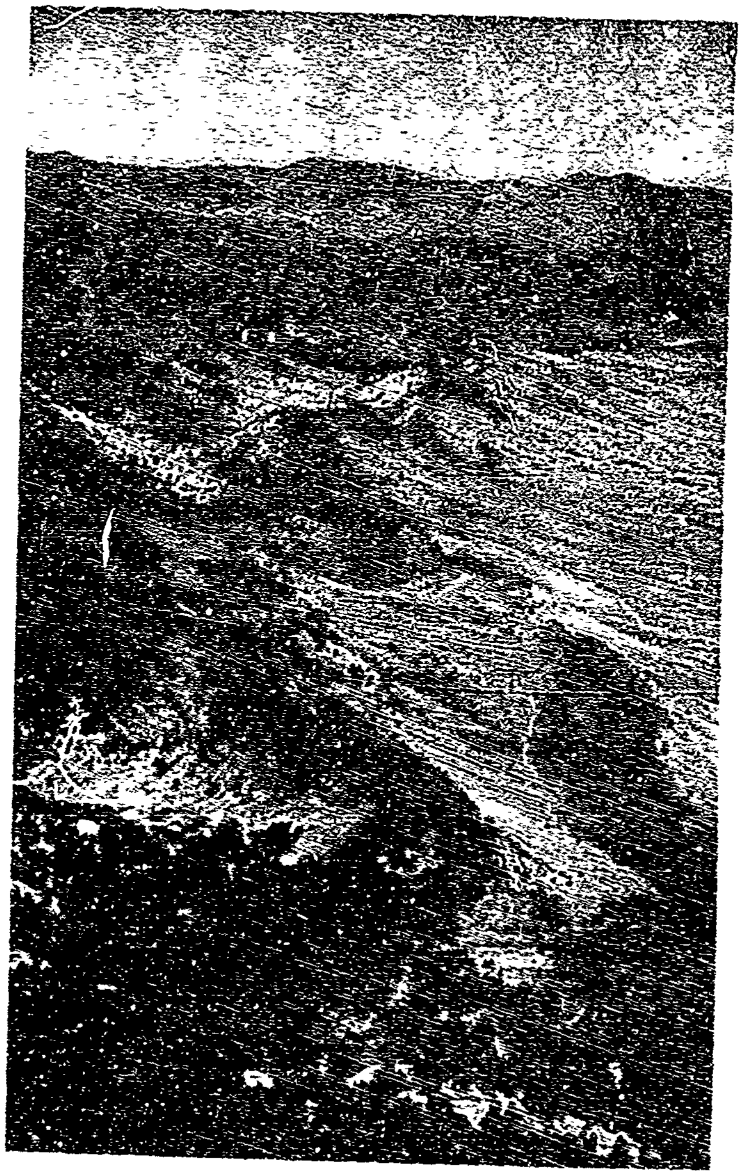


Figure 70. The edge of the plains north of Boulder, Colorado

to be determined by the change from coarse mountain soils on slopes to fine alluvium at their foot and on the plains. The view was taken from the 8,000-foot sandstone crest of the Boulder Flatirons, a particularly high unit of the hogbacks.

Boulder, at 5,400 feet, gets only 19.5 inches of precipitation per year, of which 3.17 falls in May. Its mean July temperature is 71°F. Its January mean temperature is 32.7°F as compared with 27.2° at Salt Lake City at the 4,220-foot level. The difference is due to westerly chinook (foehn) winds which are warmed adiabatically (that is, by the increase in atmospheric pressure) as they descend from the crest of the Front Range. Largely because of the foehn phenomenon, the difference between January and July mean temperature at Boulder is only 38.3 Fahrenheit degrees.

Associated with chinook winds at Boulder are canyon winds which have a frequency and violence similar to or greater than those associated with the onset of arctic air over the Wasatch at Salt Lake. Because anemometers have seldom been well placed to measure the full strength of such local winds, and because the instruments are seldom designed for winds of great violence, our records of canyon winds have not been good. However, measurements over 100 miles per hour were reported from Boulder during January 1969.

XVII. Military Summary: Environment in a Study Transect of the Utah and Colorado Rockies

From the landscape photographs, maps, discussion and data presented here it should be evident that whereas ground warfare is possible in terrain such as the southern and central Rockies, it presents some difficulties. The military forces most affected by such problems would be large ones seeking to take advantage of their size and of advanced technology.

It is suggested, however, that because of the strategic position in the Old World of analogous mountain terrain, as well as of much which is similarly rugged or more so but has somewhat different climates, it might become necessary for the U.S. Army to face those difficulties. The way in which they can be met has already been demonstrated in combat in the relatively low but rugged mountains of Korea and particularly in those of Vietnam.

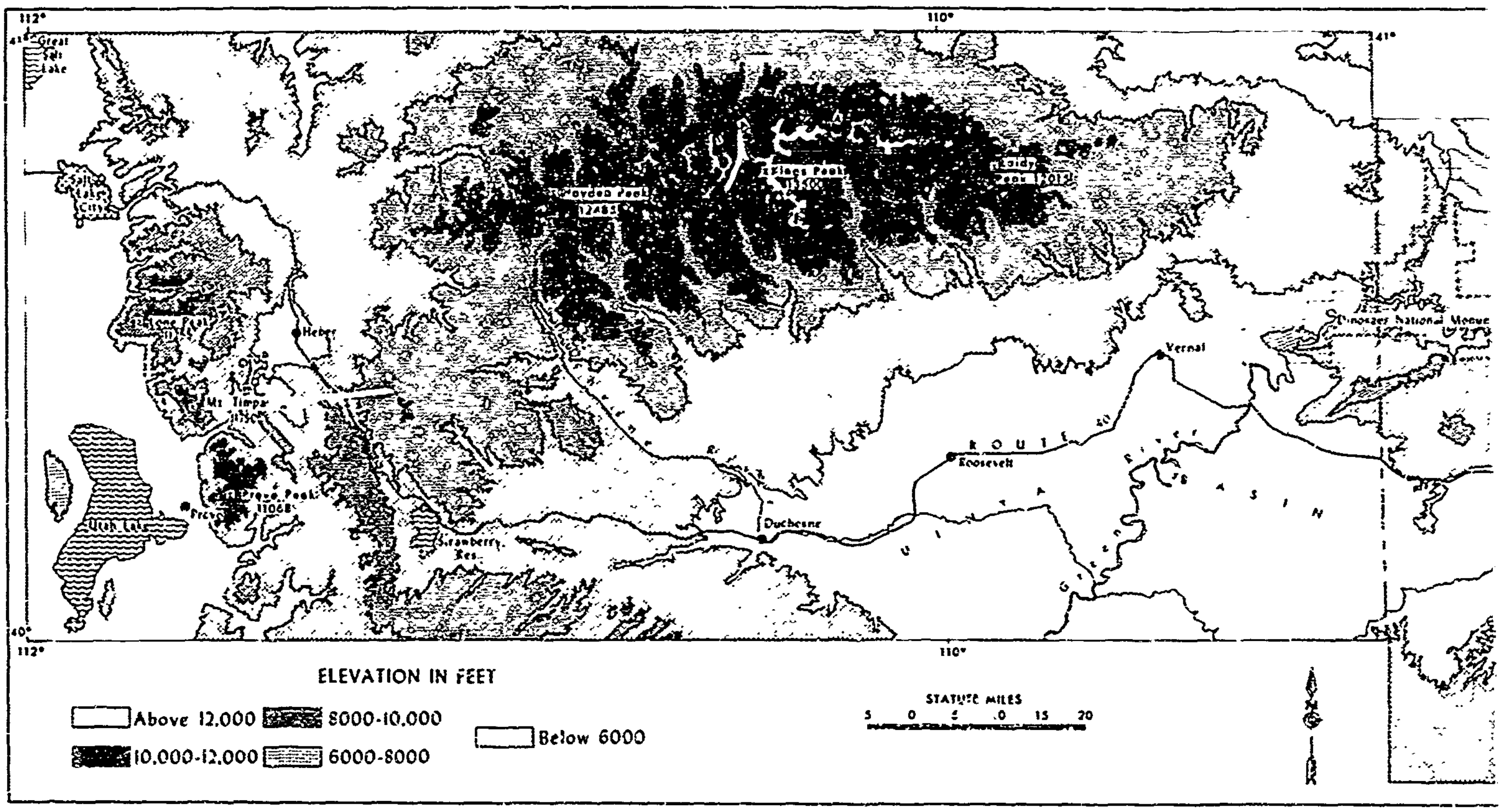
Such terrain in Central Asia and elsewhere in Eurasia has seen many wars. Large regular forces have never been able to operate successfully in the face of determined small-unit opposition in its more rugged parts, however. Historically, large forces have either reached decision without entering such terrain, have traversed it with little organized opposition and carried out decisive operations on less difficult ground beyond, or have abandoned the high mountains to any force capable of determined and well-conceived small-unit operations in their defense. Major powers have seldom gained control of such ground in the Old World without the acquiescence, or capitulation without serious resistance of some important part of its population.

Without discussing aeronautical technology in detail as it applies to the problem, but with due consideration for current steady progress of the altitudinal and load-carrying capabilities of helicopters in particular, it is suggested that past problems of large-unit operations in rugged high mountains may soon be overcome. For the present, it can be argued that mountain ranges themselves are not primary military objectives, but that some troop involvement in mountains will follow any airmobile invasion of basins among ranges such as those which make up the trans-Eurasian frontier zone. It would seem to be practicable even at the present time for any major power to establish an airhead in any lightly defended high basin below alpine levels on that frontier and to defend it by helicopter lift of troops to critical passes and commanding crests in the surrounding ranges. Military resources presently available to regimes along the axial Old World frontier zone in Asia, at least, would probably not be adequate at most points to counter such a move before the airhead was well established.

It is suggested that, if possible, U.S. Army personnel concerned with such matters continue their study of this presentation during a visit

to various parts of the study transect described here. Although the scale of mountain terrain is never fully perceived in a photograph, a guide such as this one can help explain the features seen in the field and can broaden the observer's realization of their geographic and strategic significance.

ENVIRONMENT IN A STUDY TRANS



A

TRANSECT OF THE UTAH AND COLORADO ROCKIES

TOPOGRAPHY AND LOCATION OF FEATURES

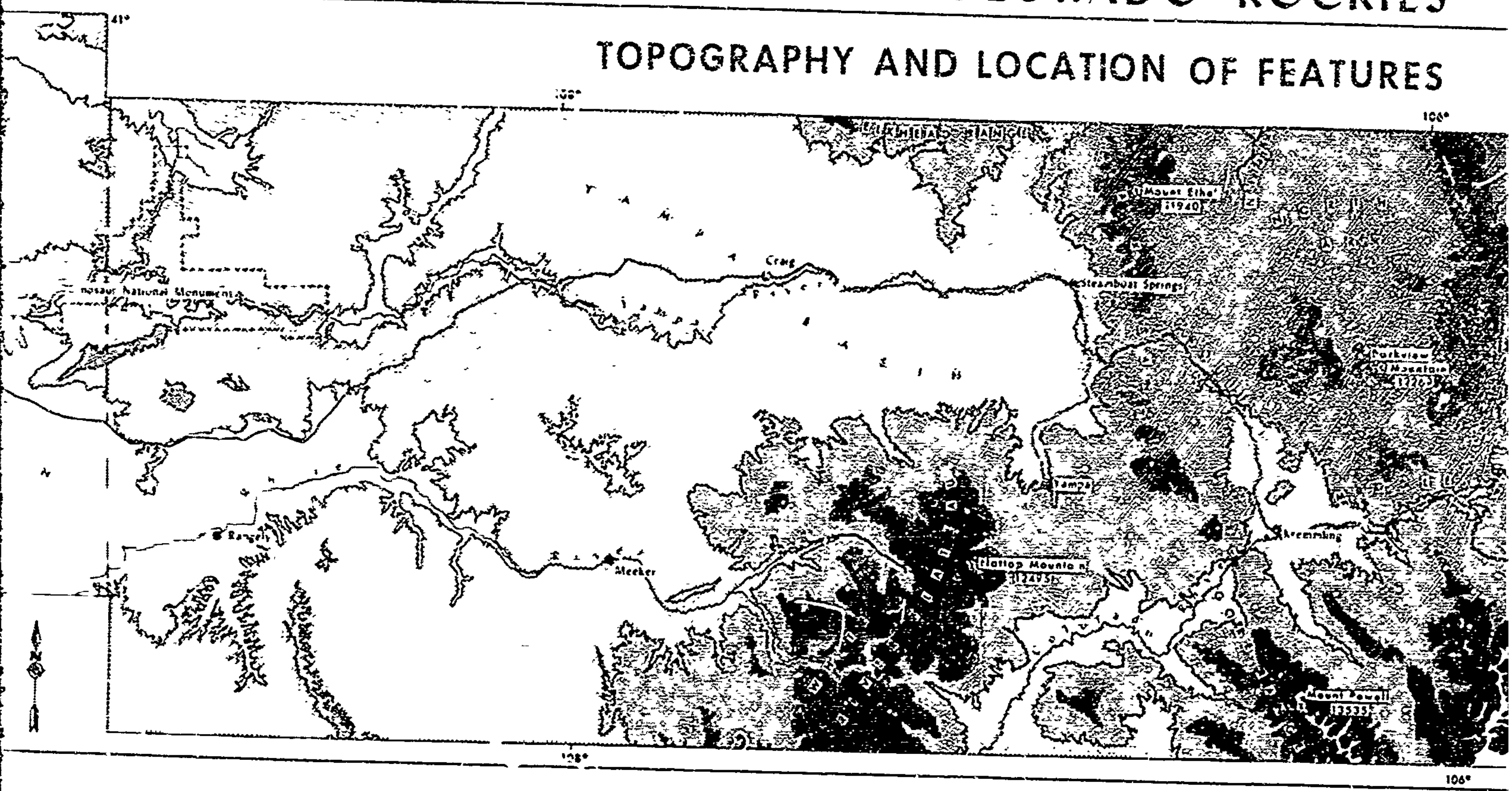
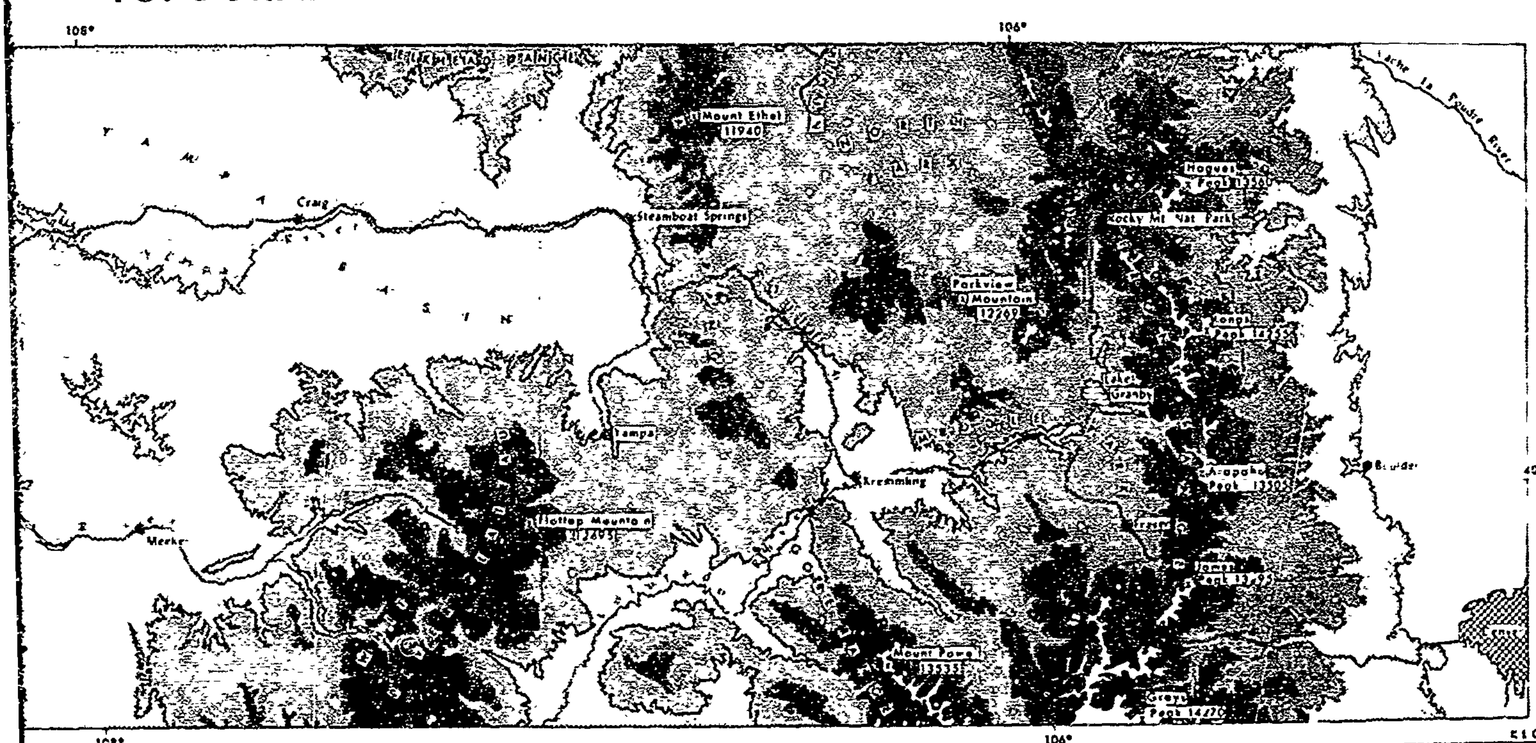


Figure 71

b

HE UTAH AND COLORADO ROCKIES

TOPOGRAPHY AND LOCATION OF FEATURES



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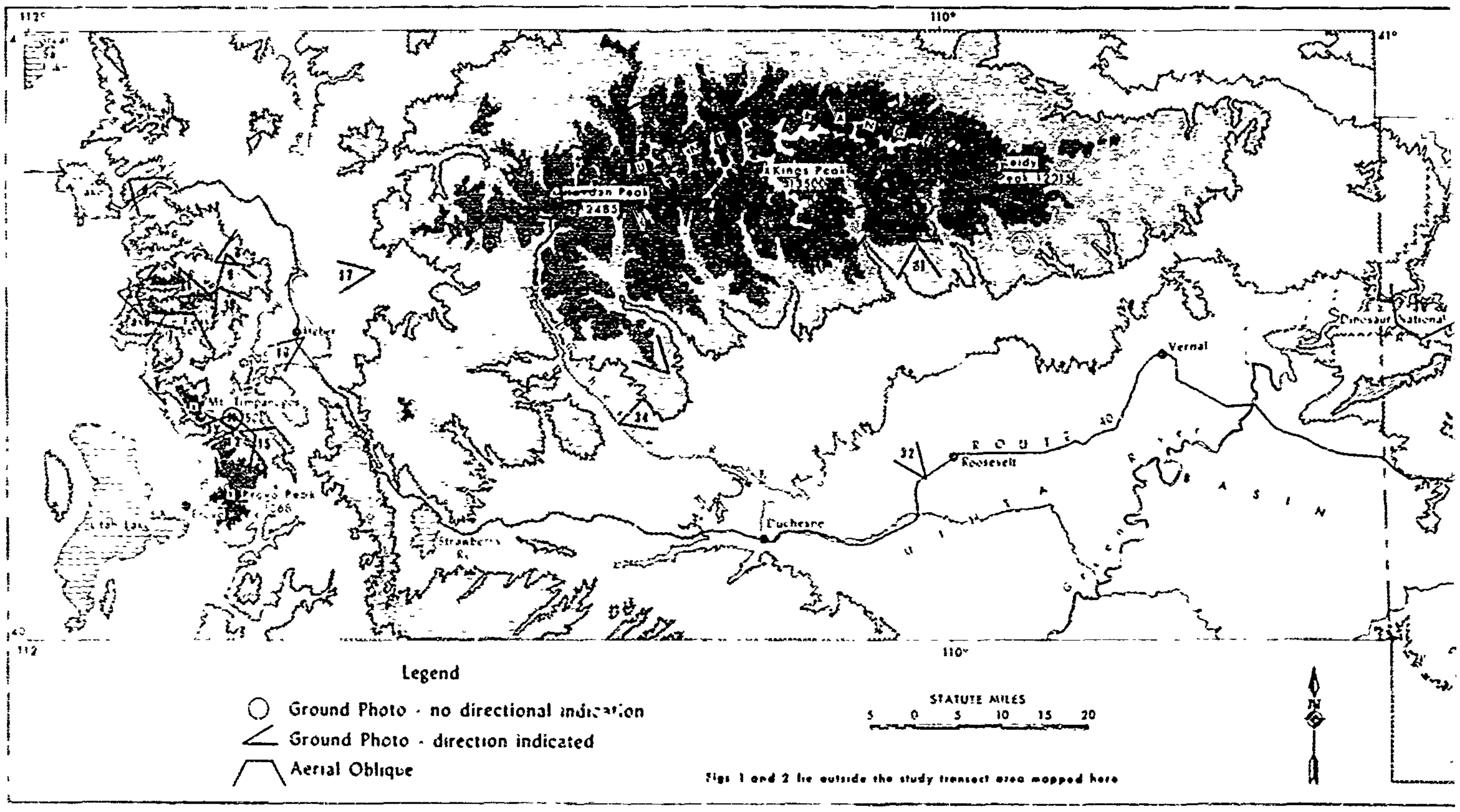
ENVIRONMENT IN A STUDY TRAN



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TRANSECT OF THE UTAH AND COLORADO ROCKIES

LOCATION OF PHOTOGRAPHS

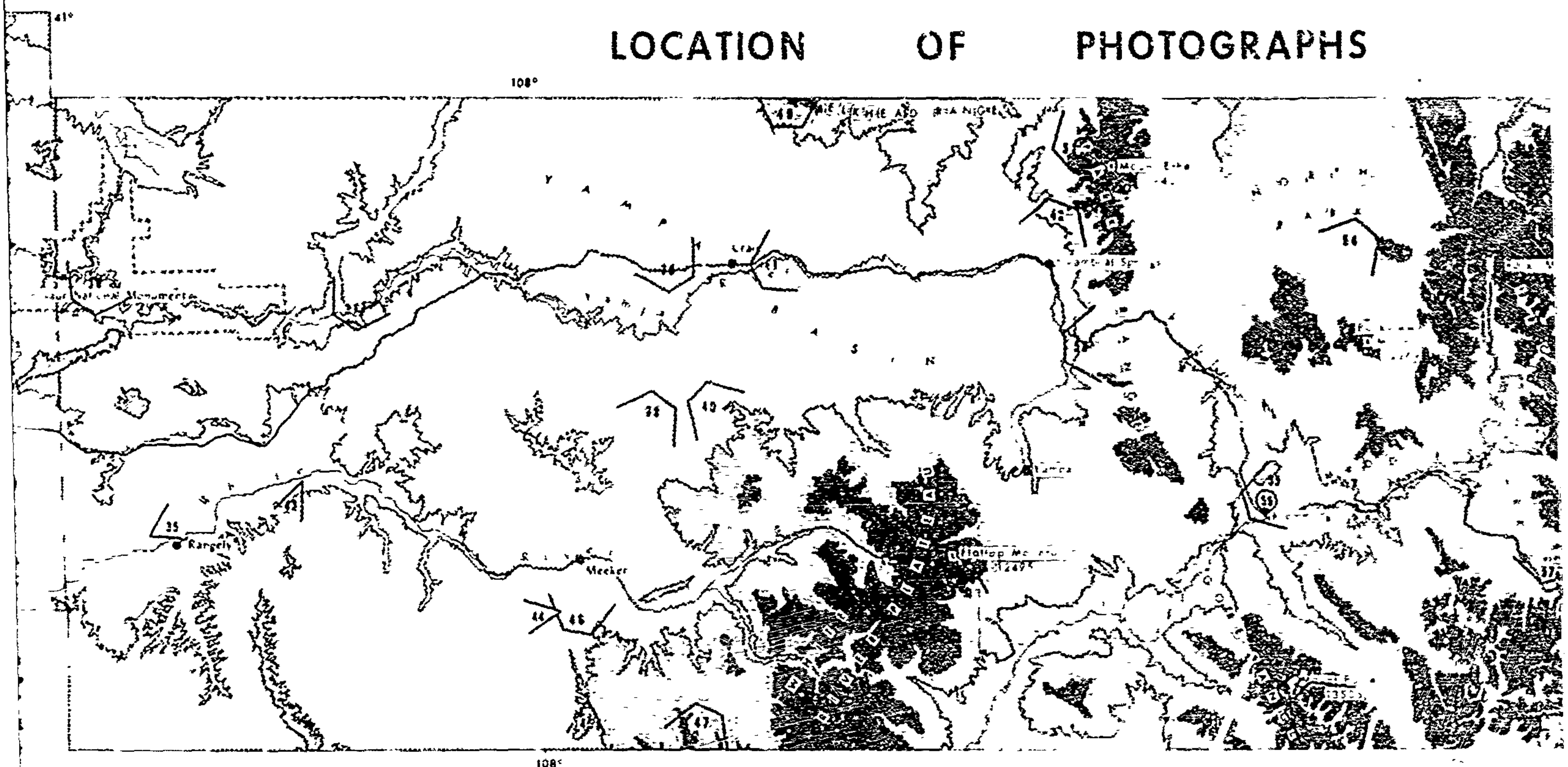
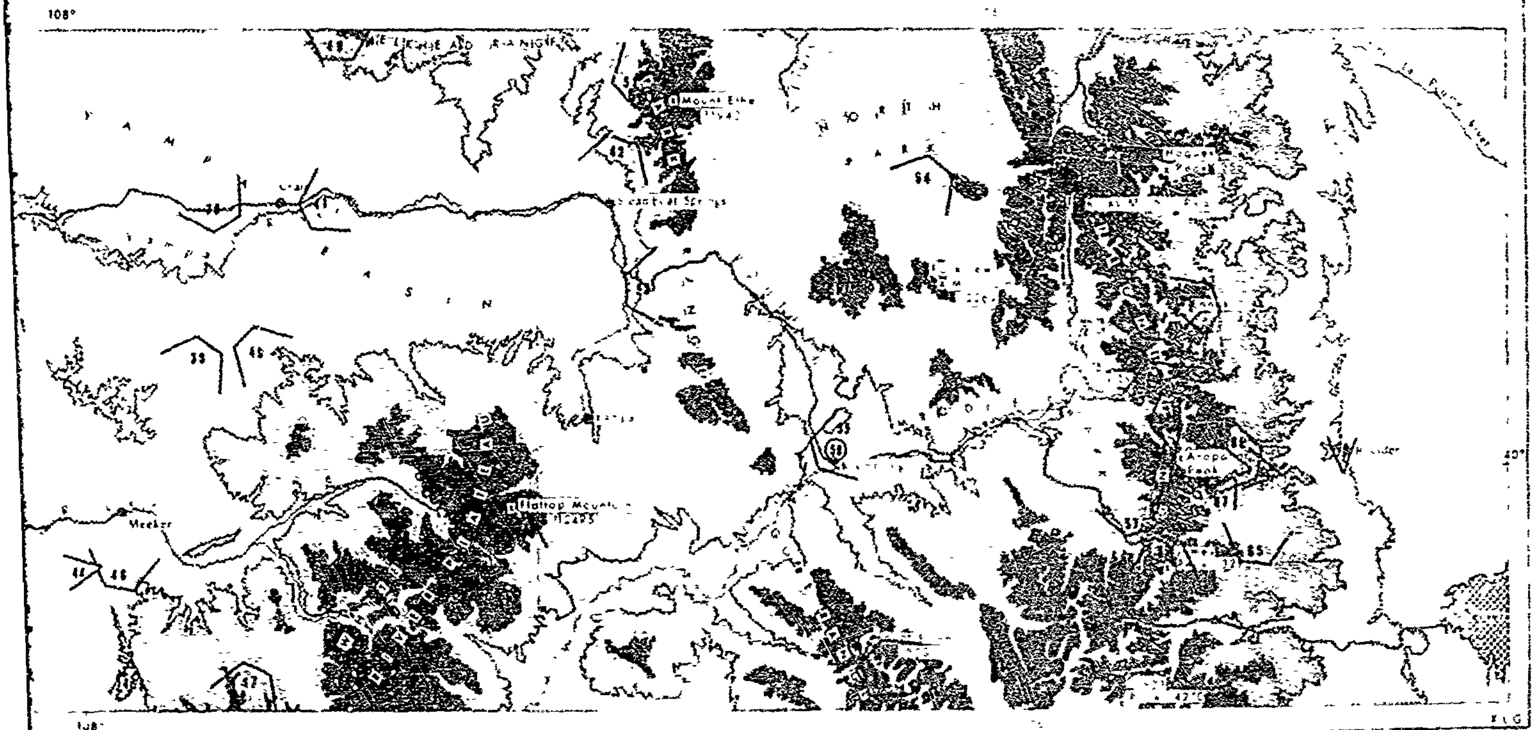


Figure 72

E UTAH AND COLORADO ROCKIES

LOCATION OF PHOTOGRAPHS



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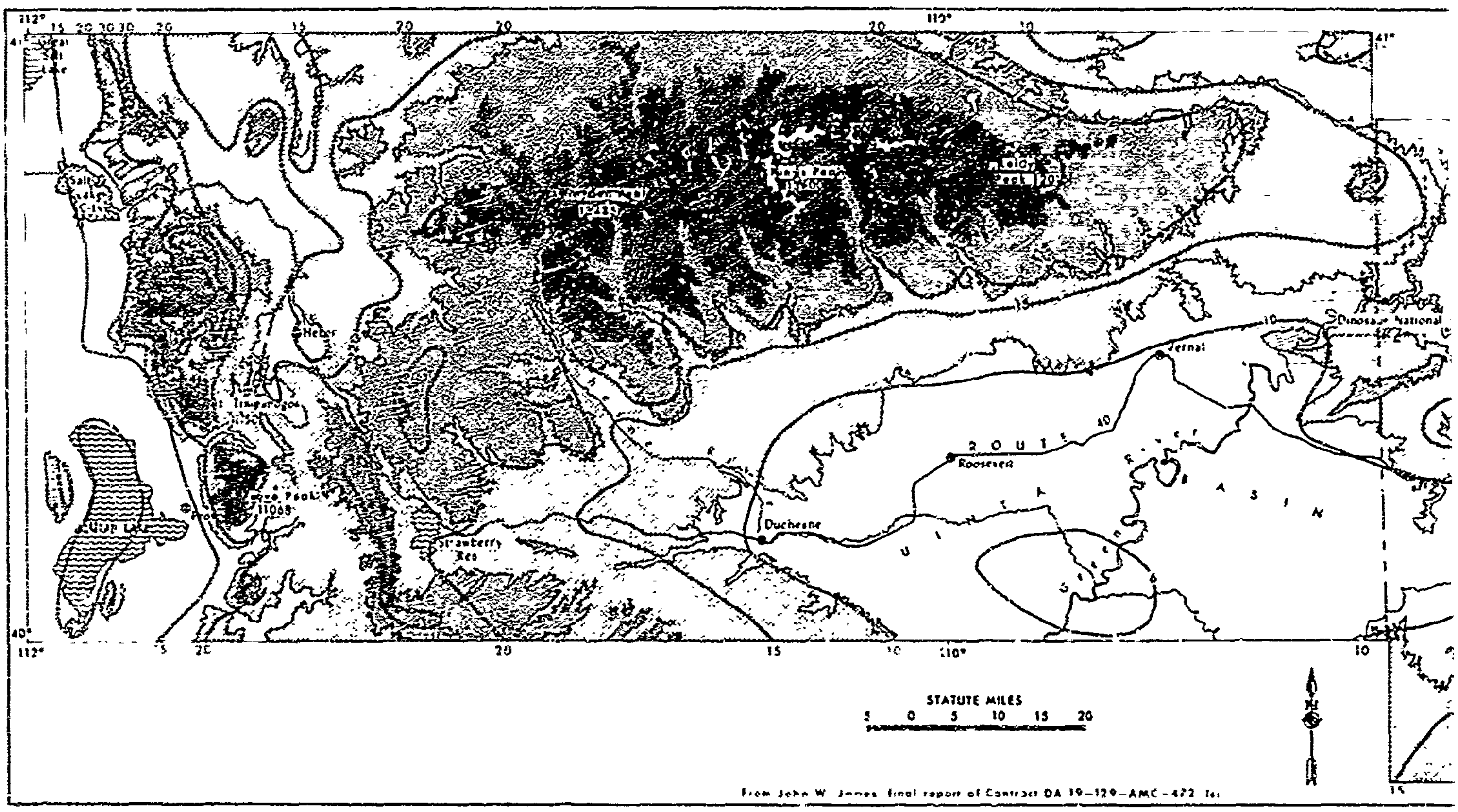

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RANSECT OF THE UTAH AND COLORADO ROCKIES

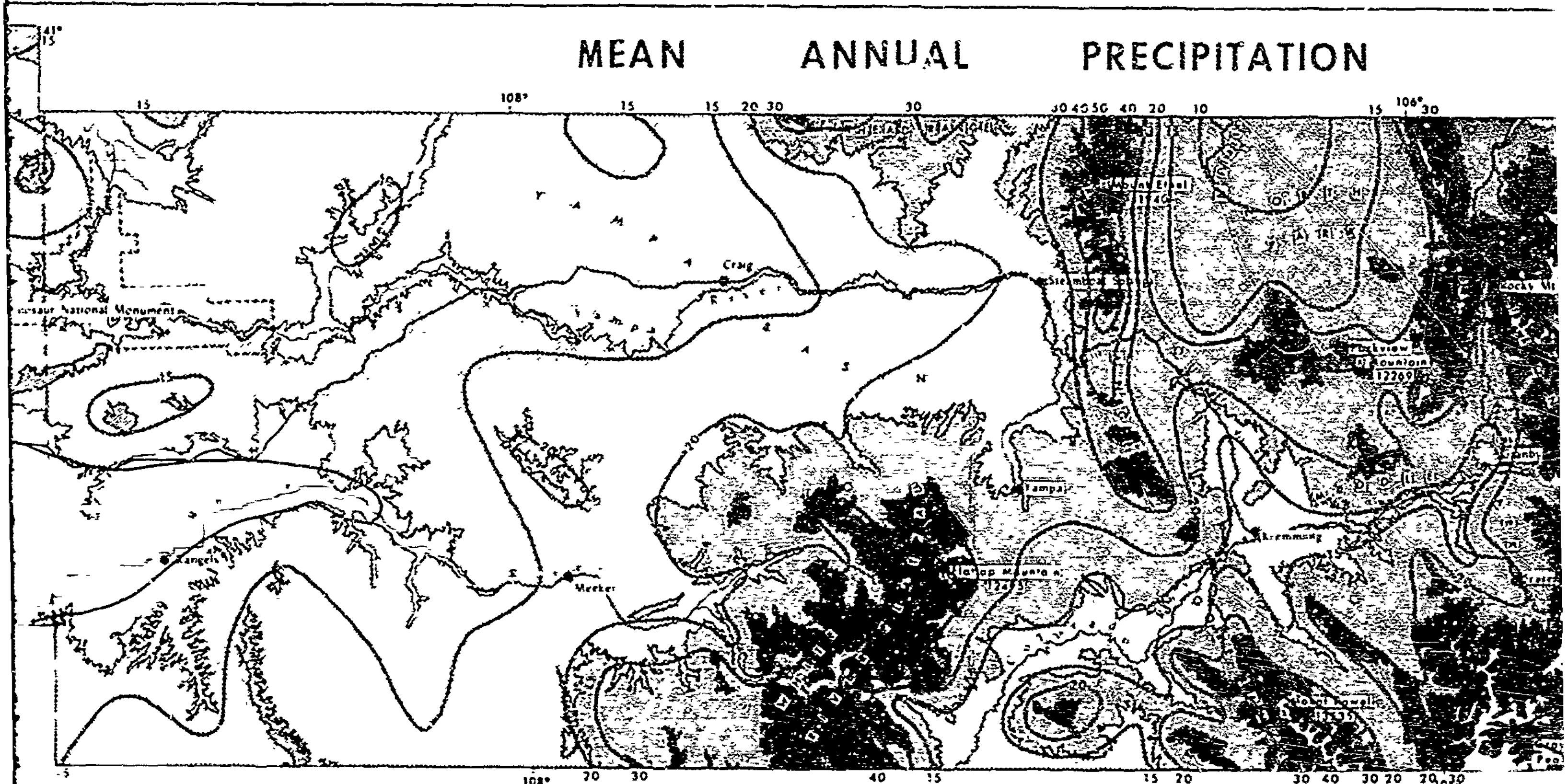
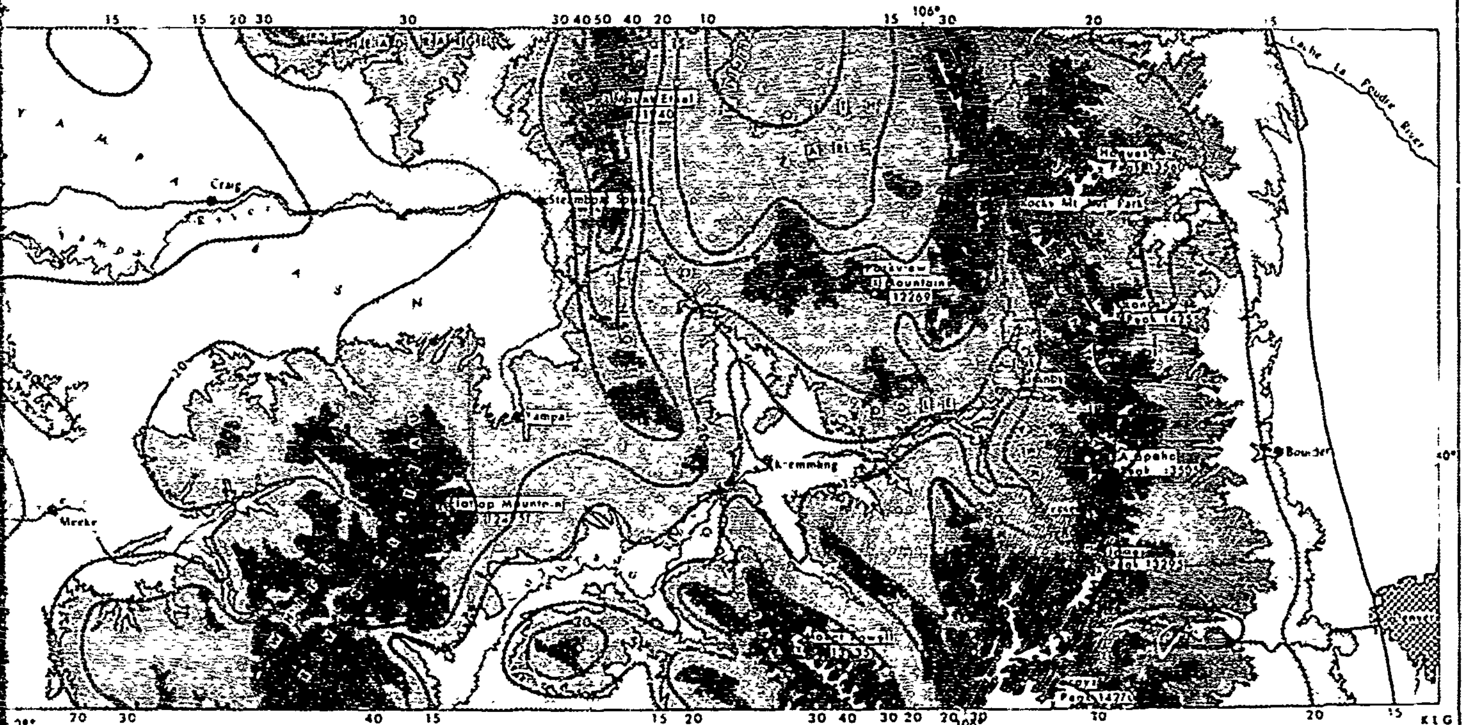


Figure 73

UTAH AND COLORADO ROCKIES

MEAN ANNUAL PRECIPITATION



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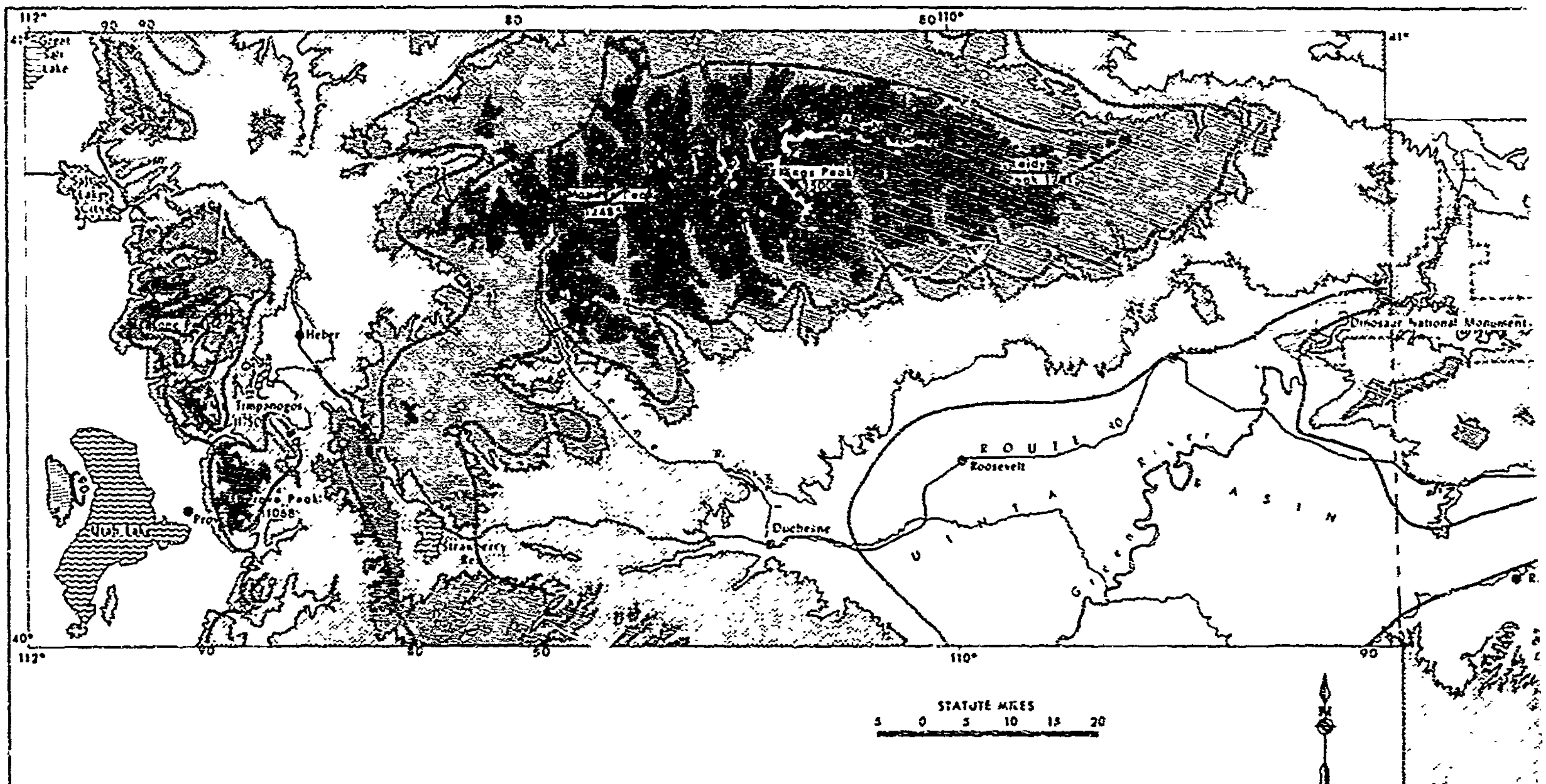


From John W. James Final report of Contract DA 19-129-AMC-472 (N)

A

ANSECT OF THE UTAH AND COLORADO ROCKIES

JULY MEAN DAILY MAXIMUM TEMPERATURE (°

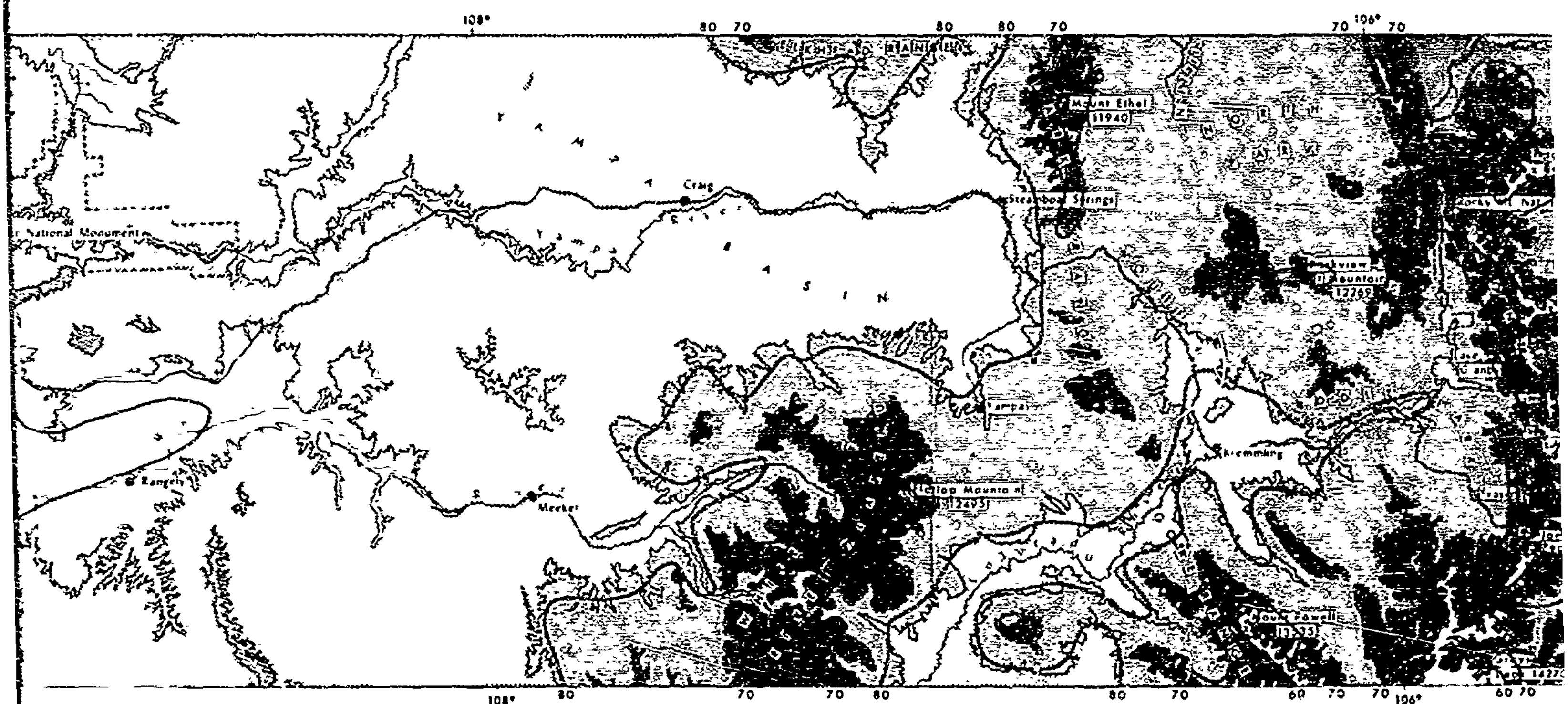
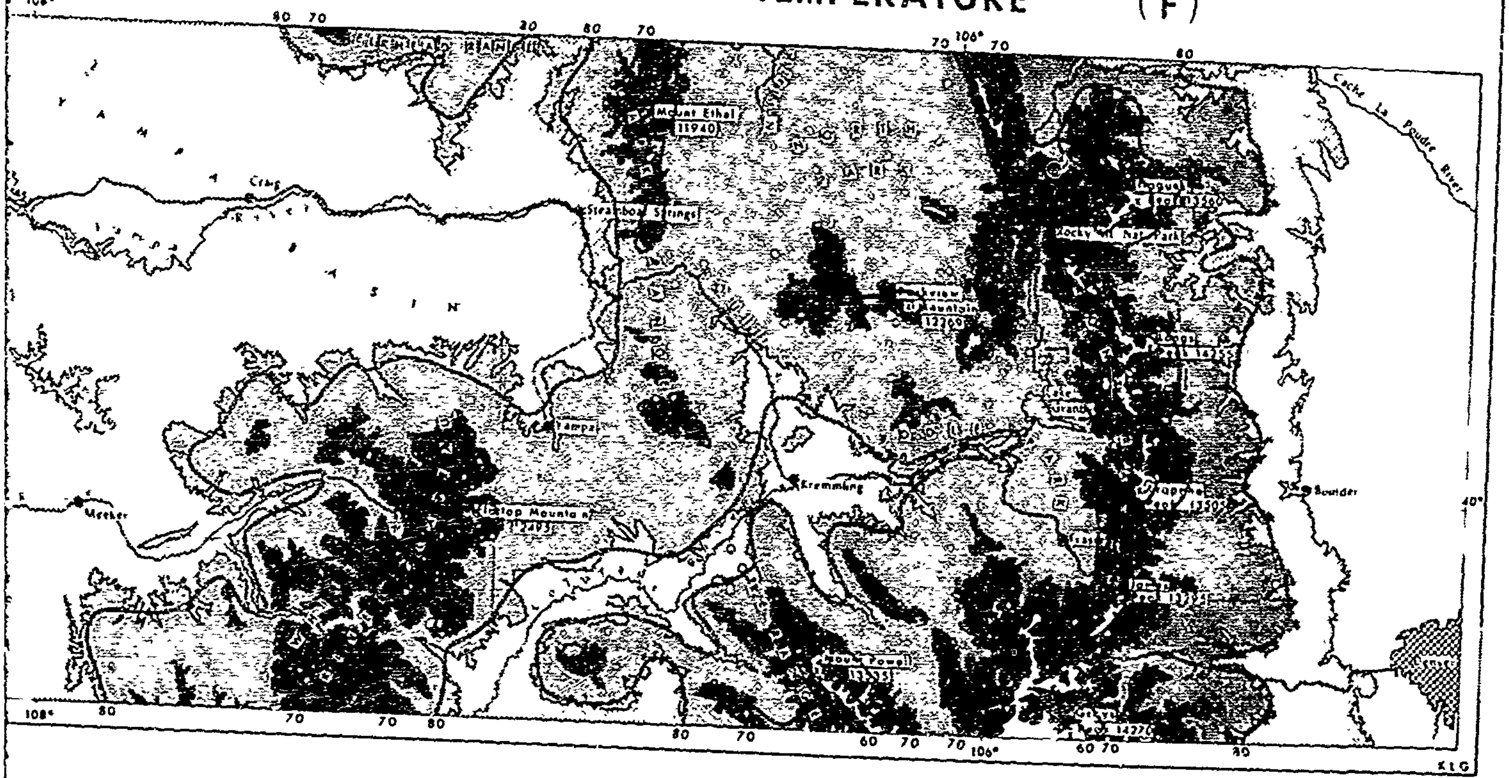


Figure 74

E UTAH AND COLORADO ROCKIES

EAN DAILY MAXIMUM TEMPERATURE (°F)



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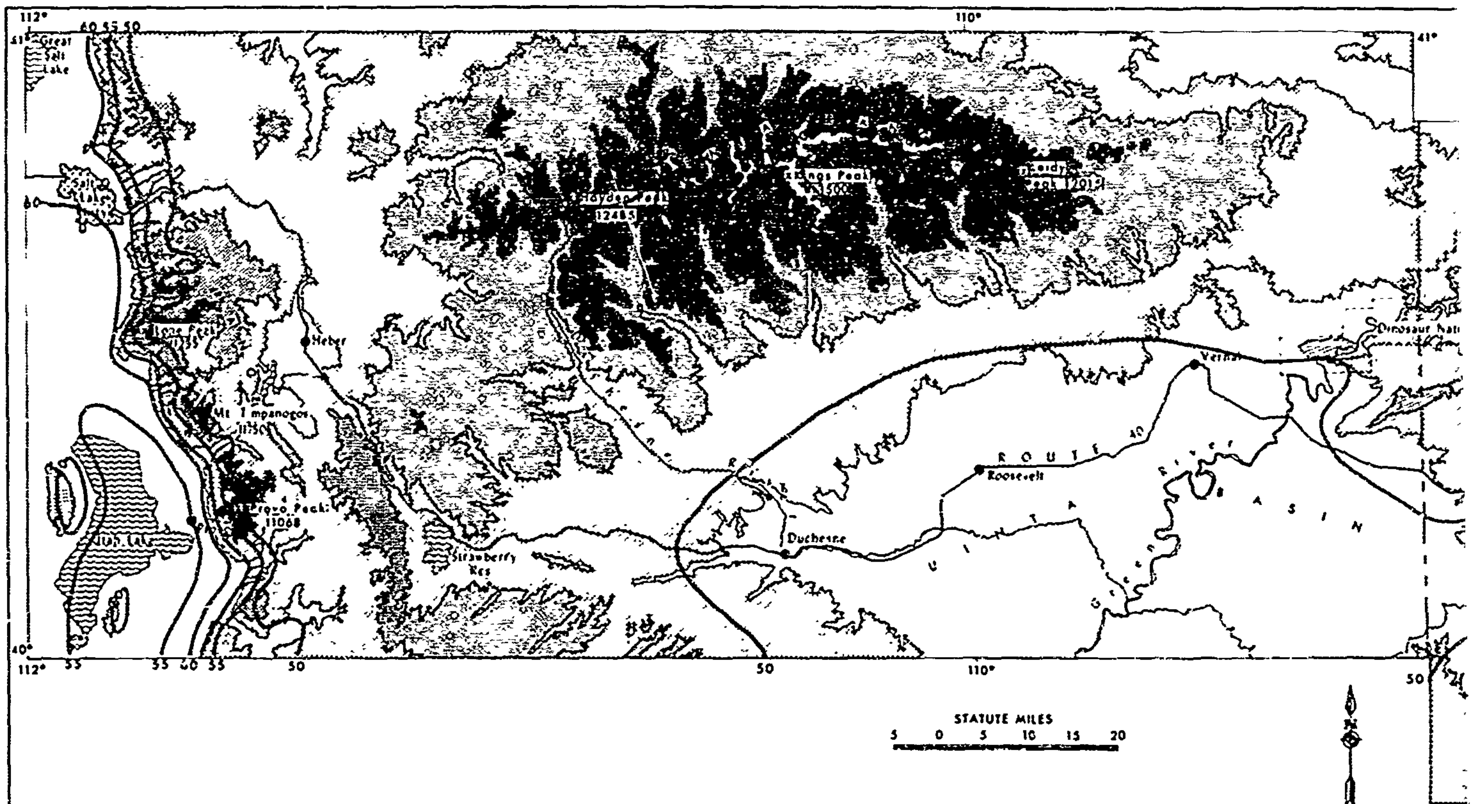

From John W James, final report of Contract DA 19-129-AMC-472 (N)

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TRANSECT OF THE UTAH AND COLORADO ROCKIES

JULY MEAN DAILY MINIMUM TEMPERATURE

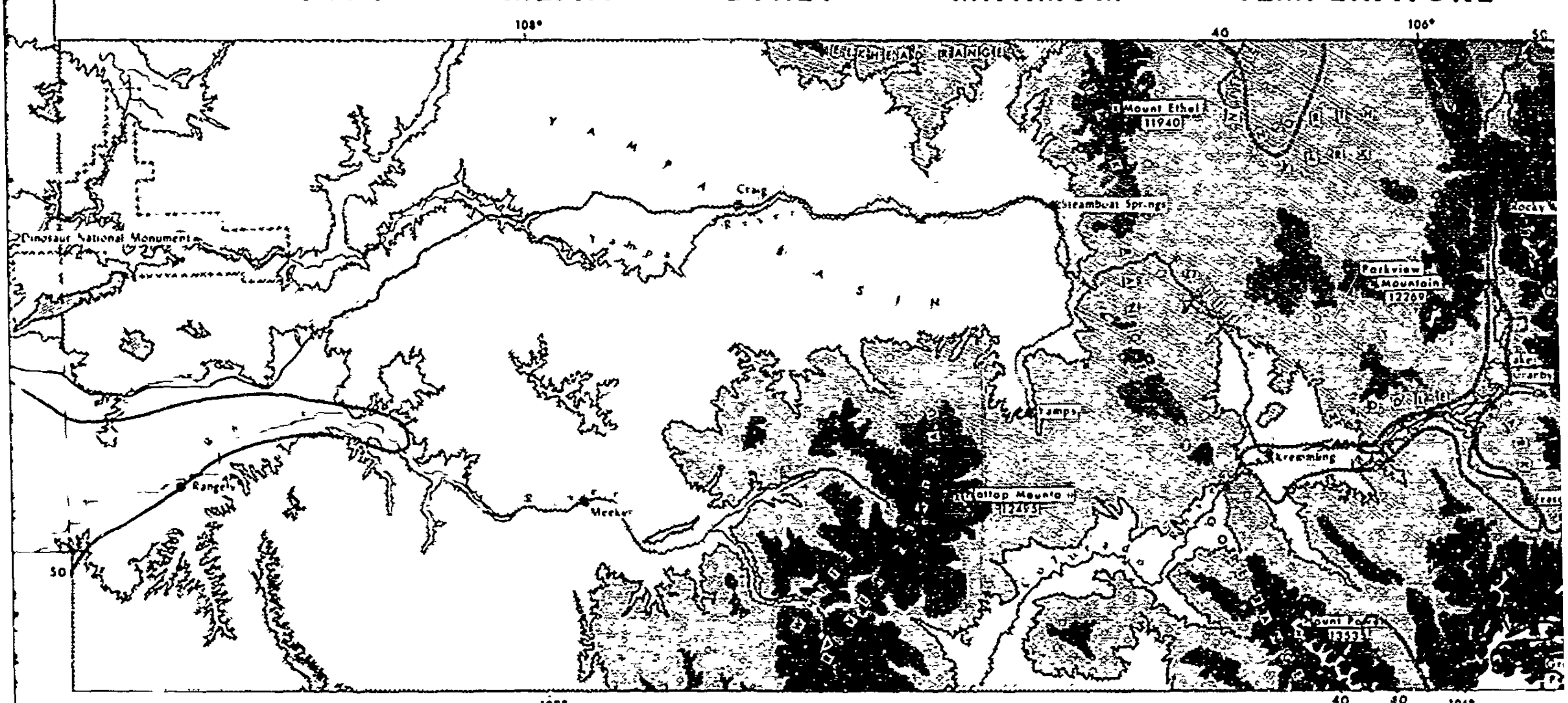
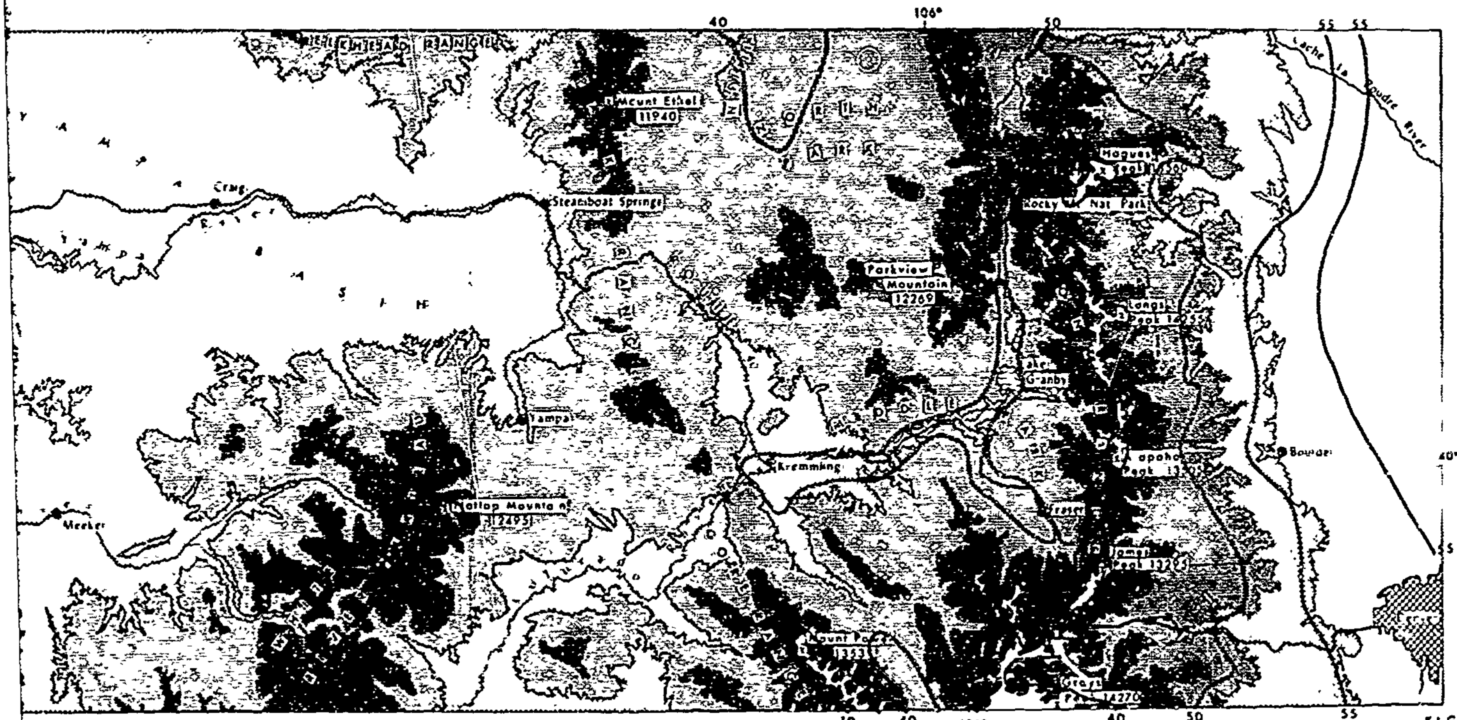


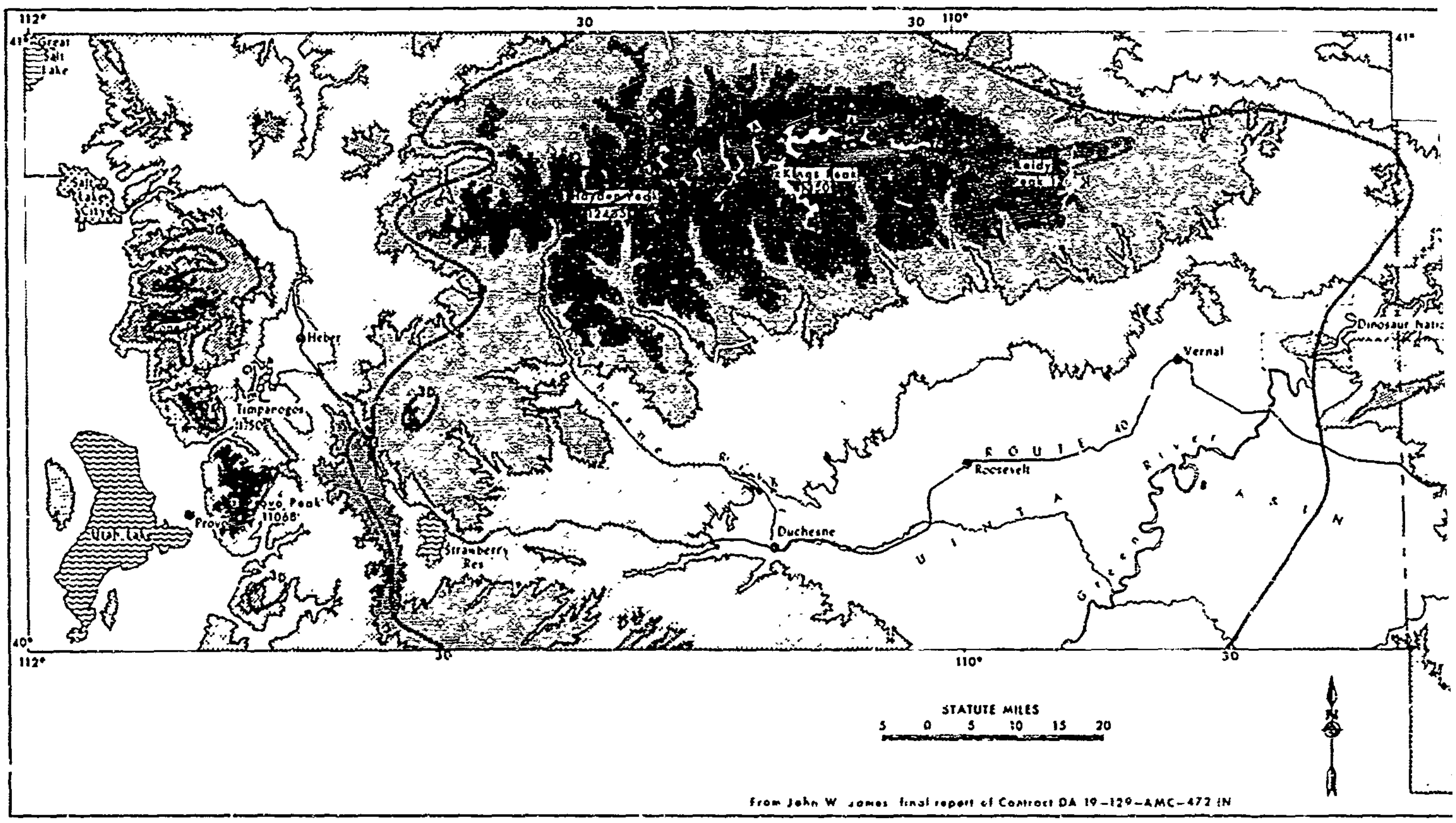
Figure 75

UTAH AND COLORADO ROCKIES

EAN DAILY MINIMUM TEMPERATURE (°F)



ENVIRONMENT IN A STUDY TRA



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Y TRANSECT OF THE UTAH AND COLORADO ROCKIES

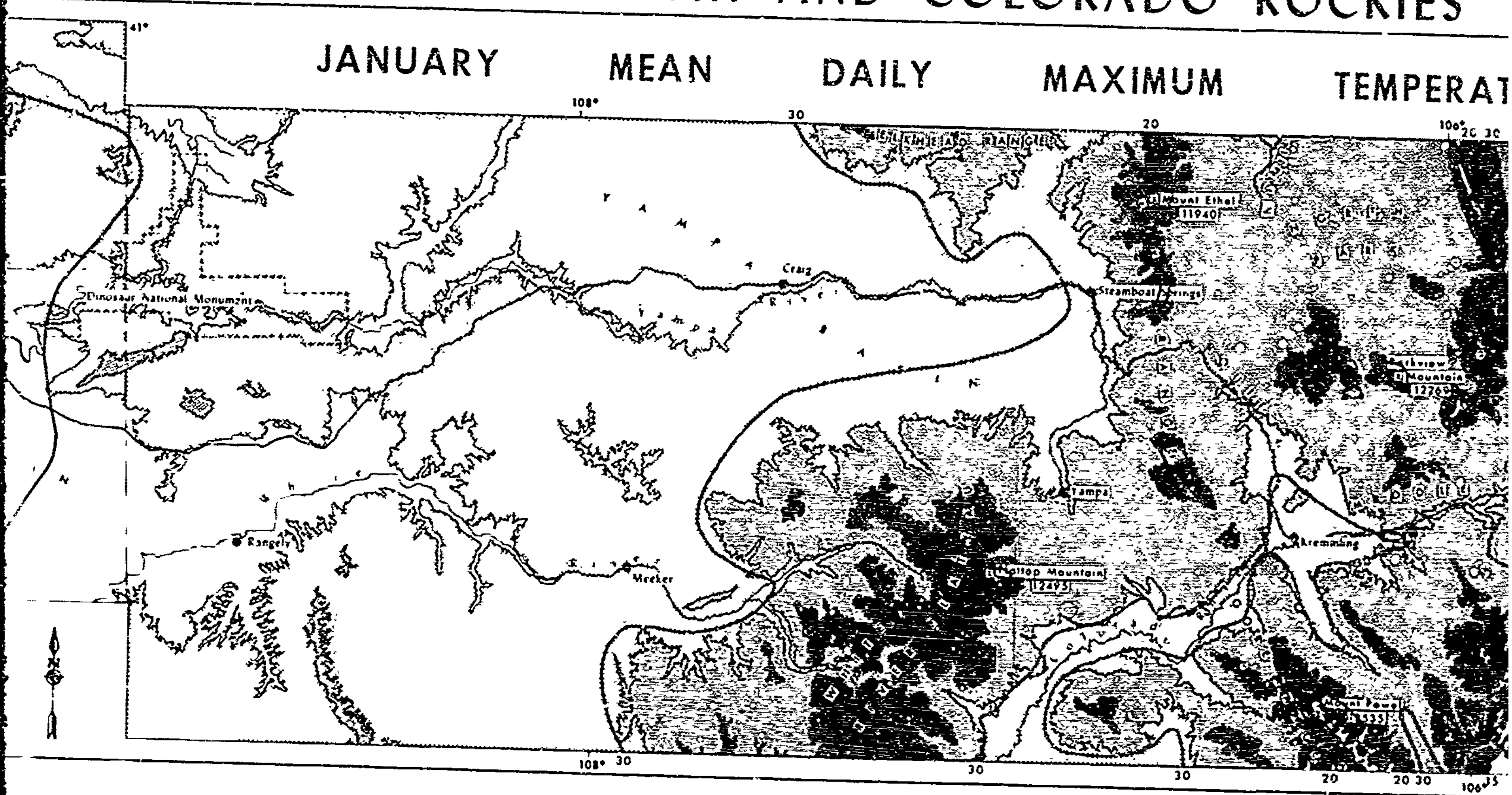
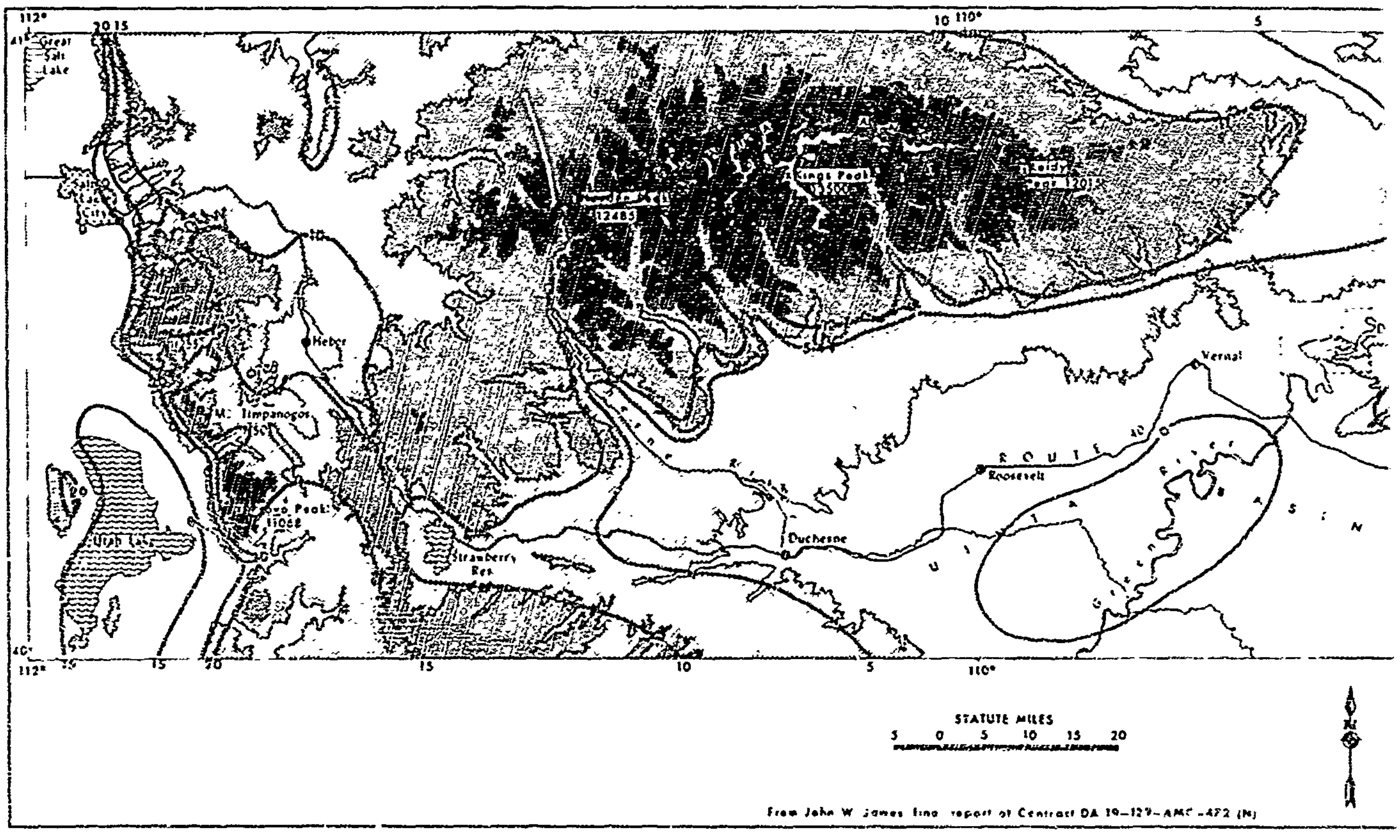


Figure 76

UTAH AND COLORADO ROCKIES

MEAN DAILY MAXIMUM TEMPERATURE (°F)

ENVIRONMENT IN A STUDY T



From John W. James final report of Contract DA 19-129-AMC-472 (N)

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DY TRANSECT OF THE UTAH AND COLORADO ROCKIES

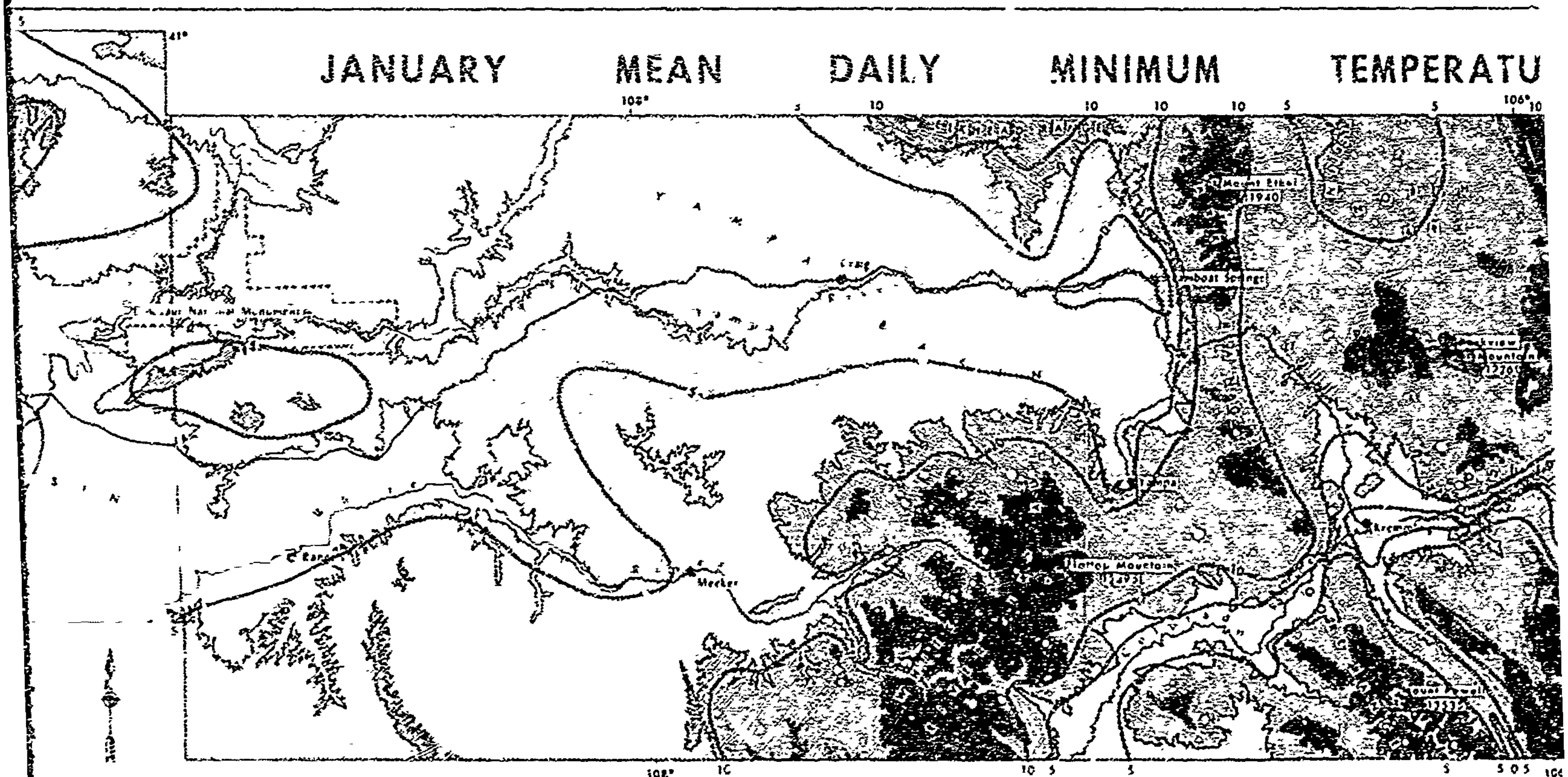
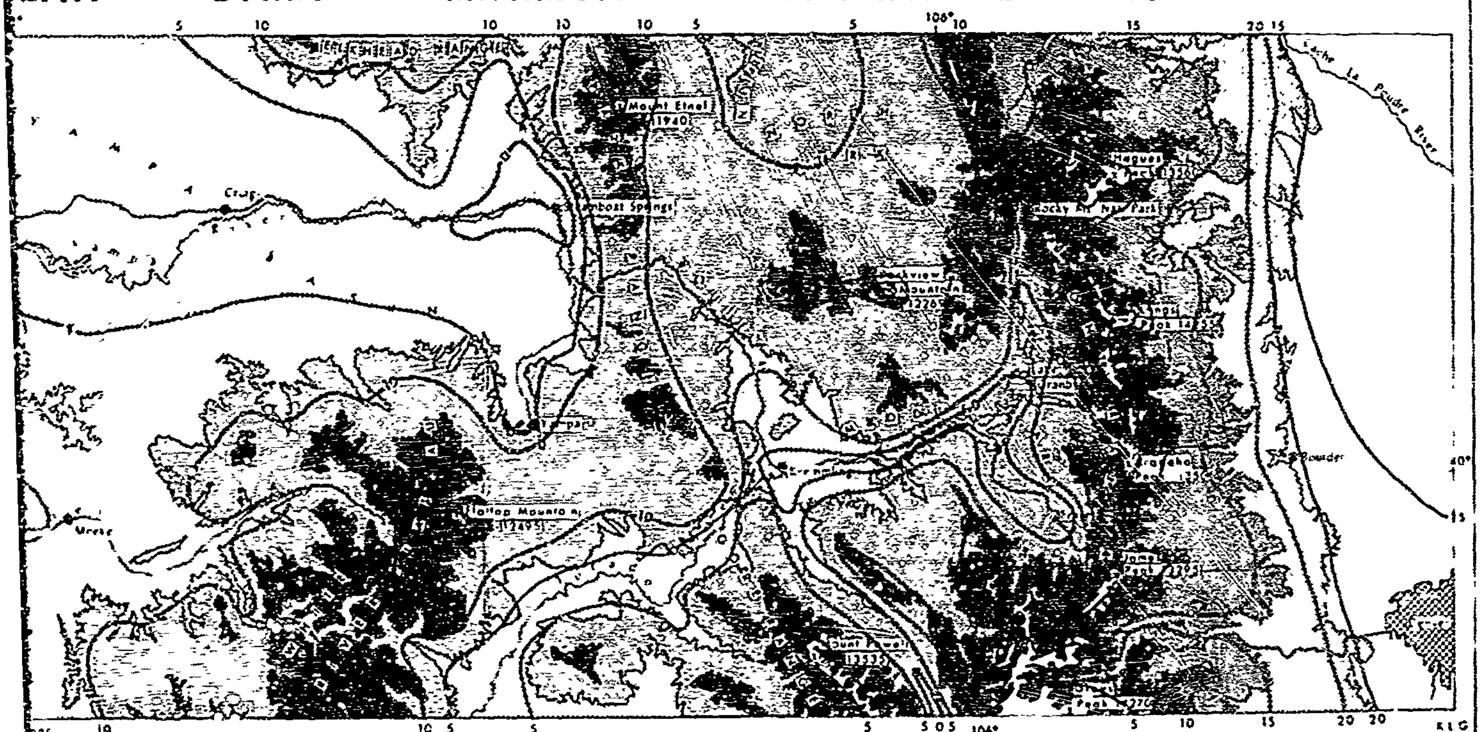


Figure 77

UTAH AND COLORADO ROCKIES

EAN DAILY MINIMUM TEMPERATURE (°F)



LOCAL RELIEF IN THE COLORADO-UTAH STUDY TRAN!

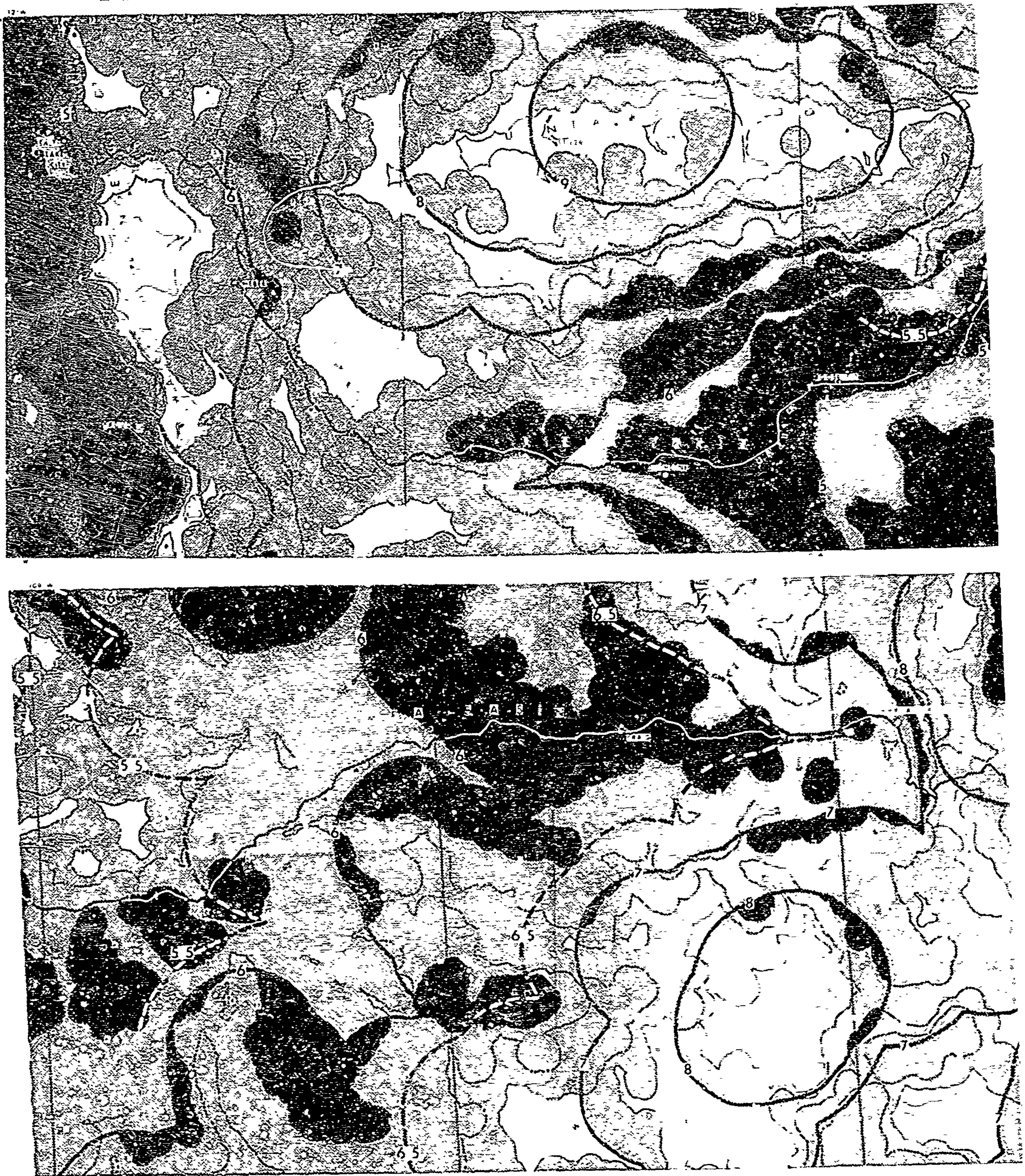


Figure 78

TAH STUDY TRANSECT

LEGEND

— GENERALIZED CONTOURS FOR PLATEAU HEIGHT. INTERVAL 1000 FEET.

— GENERALIZED CONTOURS FOR SUMMIT HEIGHT. INTERVAL 1000 FEET.

LOCAL RELIEF IS THE DIFFERENCE IN ALTITUDE BETWEEN THE PLATEAU AND SUMMITS RISING ABOVE IT.

MAP SYMBOLS ARE AS FOLLOWS:

5000 TO 8000 FEET OF LOCAL RELIEF

3000 TO 6000 FEET OF LOCAL RELIEF

1000 TO 4000 FEET OF LOCAL RELIEF

ZERO TO 2000 FEET OF LOCAL RELIEF

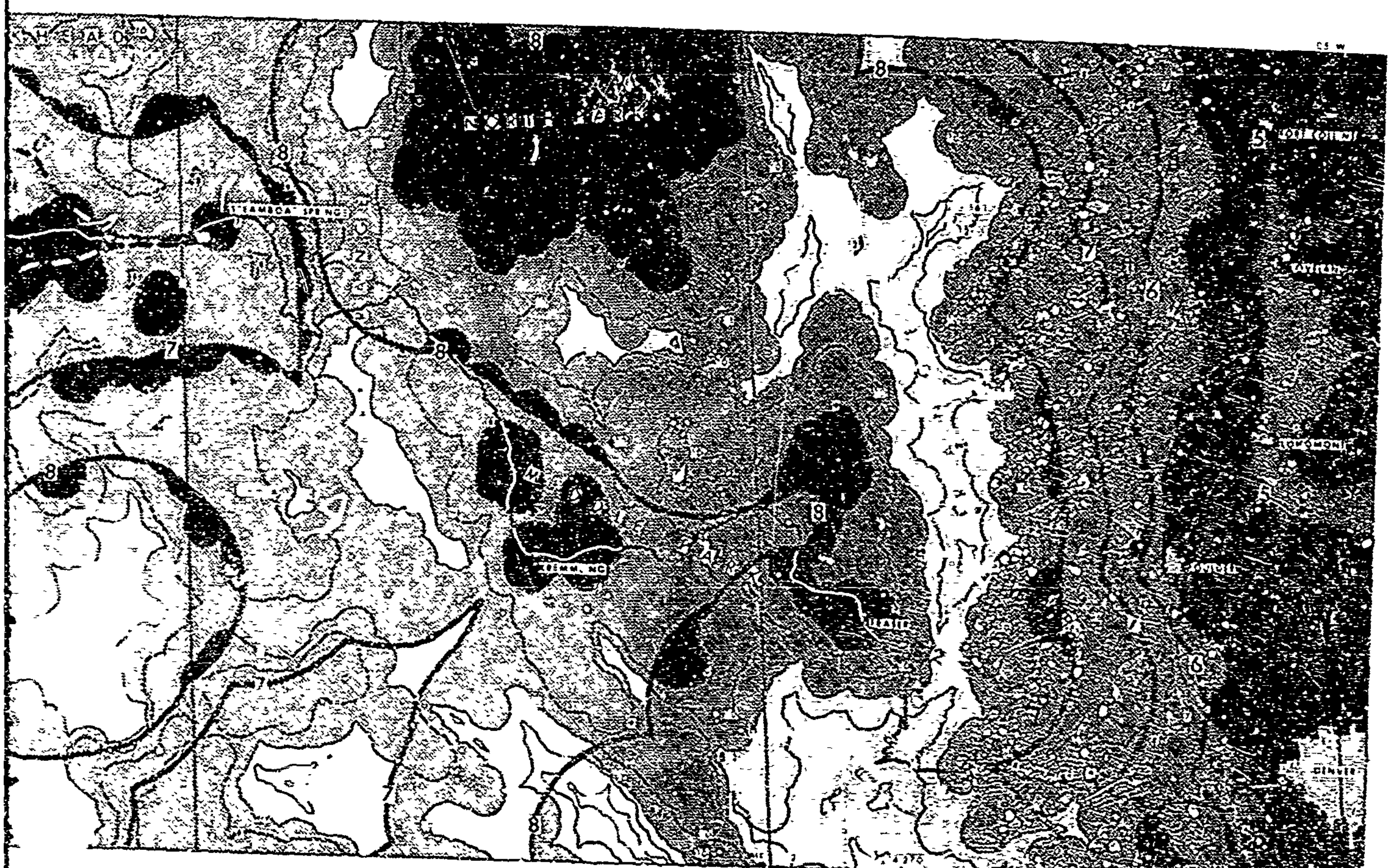


Figure 78

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This bibliography includes the greater part of that submitted with the final report of the transect contract, plus publications which have since come to hand. It is thus a fairly complete summary of scientific publications pertinent to the physical environment of the transect, plus enough material on adjacent regions to permit valid comparisons. Originally submitted under three headings, the bibliography has been unified here. Only a partial recheck of references has been possible. A relatively small number of errors has been corrected; some surely remain.

The contract bibliography has been edited with a light hand for publication here because there are few aspects of regional physical environment which the Army may not be concerned with at one time or another. Whereas the illustrations and text which make up the rest of this report are designed for a very broad readership within the Army, publication of the bibliography is considered justified by its possible usefulness to military photointerpreters dealing with analogous environments, to academic specialists doing contract studies in support of military photo-interpretation and operational planning, and to those military officers who have some background in the earth sciences and field biology.

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In this report, oak stands are classified as clumps, thickets or intermediates and quantitative data are given for age, size, and density of oak. Comparisons are made of soils and ground cover

under oak and in openings, and brief consideration is given to the effect of fire and other disturbances in oak stands.

About half the oak stems in a normal stand are less than 10 years old and the average mature stem is about 13 feet high and 3 inches in diameter. Oak stands are most dense when young, especially following a fire or other disturbance that stimulates reproduction. Soil factors do not appear to limit the distribution of oak brush. Moderate soil movement was evident in openings between clumps, but little or no movement was observed under oak.

The general extent of the oak type in western Colorado was not thought by Brown to be greatly different today than it was in the late 1800's.

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A subjective classification system was developed to evaluate the reliability of measurements of precipitation occurring primarily as snow in relation to the exposure of the gage. This system was used in classifying 30 sites at about 8,000 feet in Utah where both precipitation measurements and snow surveys are made. Differences related to exposure were found up to 81% in very windy sites. Comparisons of sheltered and unsheltered gages at Climax, Colorado, showed 36.48" to 46.25" variation for 3 winters, but summer periods were comparable, 22.39" to 22.49".

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The author considered the deciduous oaks of the mountain brush communities in Utah to be only one species, Quercus gambelii. In this species the most common form of vegetative reproduction is the formation of new stems from rhizomes, but layering also occurs. Seedlings of Gambel oak are rarely found, possibly because the acorns have a high prevalence (87% to 89%) of destruction by larvae of Lepidoptera and Coleoptera.

At its upper limit, Gambel oak may be inhibited in its spreading because of the short growing season. It occurs at altitudes of 9,000 to 10,000 feet where the growing season is usually between 60 and 90 days, but at these altitudes acorns rarely mature. Unless acorns are carried to the higher elevations by animals there is little chance of seedling development, and migration of this species must be largely by vegetative means at its upper limits.

The author discusses 1870 photographs that were repeated 70 years later. Identical oak clumps can be recognized, since the clumps are about the same shape in the later photographs as in the earlier ones. However, there is historical evidence of local increases of oak brush in Utah since settlement.

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In general, the mountain brush vegetation type has been interpreted as a stable vegetation type from both xerarch and hydrarch successional patterns. However, in this paper an exception to the general situation is discussed.

Throughout lower Provo Canyon there are small disjunct and apparently self-maintaining coniferous stands that occur within the mountain brush zone. These coniferous stands are located on steep north-facing slopes at the bases of high vertical cliffs. Near one of these coniferous stands is an example of a mountain brush stand, at an altitude of 5,100 feet, that is being invaded by white fir (Abies concolor) and Douglas fir (Pseudotsuga menziesii) rather than by other mountain brush species. No definite environmental factors were suggested as possible reasons for this unusual successional sequence. This example was interpreted as primary succession because there was no evidence of disturbance by man in this stand, although logging did occur in the early history of other parts of Provo Canyon.

_____________. 1964b. Utah botany and wild land conservation: a card file bibliography, Proc. Utah Acad. Sci., Arts and Letters 41: 144.

A bibliography of approximately 1,400 references to Utah botany and wild land management. Included are articles on botany per se, biotic communities, range and watershed management, forestry, recreational uses of wild lands, and those aspects of zoology and wildlife management that involve plant communities or habitat management. Most of the references are to scientific papers and theses, but selected semi-popular and popular articles are included.

Christensen, E. M., and H. B. Johnson. 1964. Presettlement vegetational change in three valleys in central Utah, Brigham Young Sci. Bull., Biol. Ser. 4, No. 4, 16 pp.

A careful documentation of the historical evidence of vegetation changes in Millard and Juab Counties south of the transect

study area. The authors state that the major decline of grass and invasion of sagebrush probably occurred between 1870 and 1900.

An invasion of juniper into the original grass and sagebrush zones is well documented. They also discuss sand dune migration. The invasion of tamarix (*T. Pentandra*) into the lowland areas of the valleys since 1925 is a conspicuous feature of the vegetation changes in the valleys.

Western portions of the transect study area have likely experienced vegetation changes similar to those described by Christensen and Johnson.

Clark, J. M., and E. B. Peterson. 1968. Insolation in relation to cloud characteristics in the Colorado Front Range, In: Arctic and Alpine Environments, Proceedings VII Congress, INQUA, 10: 3-11.

Clausen, J., D. D. Keck, and W. M. Hiesey. 1940. Experimental studies on the nature o. species, I. Effect of varied environments on western North American plants, Carnegie Inst. of Washington, Washington, D.C., Publ. 520, 452 pp.

Clements, F. E. 1907. The causes of dwarfing in alpine plants, Science 25: 287.

___________. 1910. The life history of lodgepole burn forests, U. S. Forest Service Bull. 79, 56 pp.

Colorado Crop and Livestock Reporting Service. 1964. Colorado growing season and freeze probabilities, spring and fall, Bull. 64-2, 28 pp. Unpublished.

Colson, De Ver. 1957. Thunderstorm analysis in the northern Rocky Mountains, Intermountain Forest and Range Exp. Station Research Paper No. 49.

Cook, A. W., and A. Topil. 1952. Some examples of chinooks east of the mountains in Colorado, Bull. Amer. Meteorol. Soc. 33: 42-47.

Cooper, C. F. 1960. Changes in vegetation, structure and growth of southwestern pine forests since white settlement, Ecol. Monogr. 30: 129-164.

Cooper, W. S. 1908. Alpine vegetation in the vicinity of Long's Peak, Colorado, Botan. Gaz. 45: 319-337.

Cormack, R.G.H. 1953. A survey of coniferous forest succession in the eastern Rockies, Forest Chron. 29: 218-232.

Costello, D. F. 1944. Important species of the major forest types in Colorado and Wyoming, Ecol. Monogr. 14: 107-134.

Costello, D. F., and R. Price. 1939. Weather and plant development data as determinants of grazing periods on mountain ranges, U. S. Dept. Agric. Tech. Bull. 686, 30 pp.

Cottam, W. P. 1929. Some phytogeographical features of Utah, Proc. Utah Acad. Sci. 6: 6-7.

____________. 1929. Man as a biotic factor illustrated by recent floristic and physiographic changes at Mountain Meadows, Washington County, Utah, Ecology 10: 361-363.

____________. 1930. Some unusual floristic features of the Uinta Mountains, Utah, Proc. Utah Acad. Sci., Arts and Letters 7: 48-49.

Cottam cited the Uinta Mountains as one of the best examples of zonal jumbling to be found in Utah. He described an area 10 miles east of Kamas where plant indicators of every temperature zone found in Utah, except the Lower Sonoran Zone, occur at approximately the same elevation and in close proximity.

Extensive stands of lodgepole pine make the Uinta Mountains the only area in Utah with a characteristic northern Rocky Mountain flora. In addition, the glacial lakes in the subalpine region of these mountains are the only bogs in Utah with a typical acid bog flora, including Sphagnum and numerous members of the family Ericaceae. The Uinta Mountains represent Utah's largest area of commercial forest, mostly of Engelmann spruce.

Cottam suggested that these mountains have served as a migratory lane for flora from the Colorado drainage and from the northern Rocky Mountains to the Wasetch Mountains and the Great Basin.

____________. 1954. Prevernal leafing of aspen in Utah mountains. J. Arnold Arboretum 35: 239.

____________. 1961 Our renewable wild lands - a challenge. Univ. of Utah Press. 182 pp.

A collection of essays which are an outgrowth of a 1947 lecture entitled, "Is Utah Sahara Bound?" by Walter P. Cottam. The report includes a review of the status of conservation in Utah at the close of the first century since settlement. The author has analyzed some of the present controversies regarding the extent of resource deterioration. The article is pertinent to the transect study areas because it includes a discussion of the history and vegetation changes within Red Butte Canyon and Emigration Canyon, within the transect area just east of Salt Lake City and with vegetation changes in the mountain meadows area of southwestern Utah.

Twenty photographs of various landscapes in Utah supplement the discussions on the relation of plant cover to the hydrologic cycle. A good documentation of man's influence in changing the landscape over a relatively short period of time.

Cottam, W. P., and G. Stewart. 1940. Plant succession as a result of grazing and of meadow desiccation by erosion since settlement in 1862. J. Forestry 38: 613-626.

Cottam, W. P., and F. R. Evans. 1945. A comparative study of the vegetation of grazed and ungrazed canyons of the Wasatch Range, Utah. Ecology 26: 171-181.

Cottam, W. P., J. M. Tucker, and R. Drobnick. 1959. Some clues to Great Basin postpluvial climates provided by oak distribution. Ecology 40: 361-377.
This article centers around the presence near Salt Lake City of oaks that seem to be hybrids between Quercus gambelii and Quercus turbinella. The latter is an evergreen shrub that just reaches into southwest Utah from the semi-arid chaparral and pinyon-juniper woodland of the southwest United States. The authors suggested that the postpluvial Altithermal period (from about 7,500 to about 4,000 years ago), which was marked by a warmer and drier climate than at present, provided suitable conditions for the northward migration of Q. turbinella. Since the Altithermal period this oak has disappeared from the area of the Wasatch front, but Q. gambelii and the hybrid oak have persisted.
The high frequency of temperature inversions along the front of the Wasatch and of the Oquirrh Mountains is offered as an explanation for the fact that the present-day lower limit of Q. gambelii is about 500 feet below the 5,400-foot level of the relict hybrids, which presumably require a warmer microclimate than the Gambel oak. The authors provide evidence to indicate that neither the evergreen Q. turbinella nor the hardier Q. gambelii could have persisted along the Wasatch front during the Wisconsin glaciation. There are also indications that, in pluvial times of the postglacial, spruce-fir forest occupied the areas above the Bonneville strandline which are now covered by oak.
There are good climatic analyses in this report and a valuable discussion of the ecology of Gambel oak in Utah.

Cowles, H. C. 1902. Ecologial problems connected with alpine vegetation. Science 15: 459-460.

Cox, C. F. 1933. Alpine plant succession on James Peak, Colorado. Ecol. Monogr. 3: 300-372.

Crawford, A. L., and F. E. Thackwell. 1931. Some aspects of the mudflows north of Salt Lake City, Utah. Proc. Utah Acad.Sci.8: 97-105.

Critchfield, W. B. 1957. Geographic variation in Pinus contorta. Maria Moors Cabot Foundation Publ. 3, Harvard Univ., Cambridge, Mass.

Crittenden, M., B. J. Sharp, and F. C. Calkins. 1952. Geology of the Wasatch Mountains east of Salt Lake City; Parley's Canyon to Traverse Range. Guidebook to the Geology of Utah, pp. 1-71.

Croft, A. R., and R. B. Marston. 1950. Summer rainfall characteristics in northern Utah. Trans. Amer. Geophys. Union 31: 84-95.

Croft, A. R., and L. V. Monniger. 1953. Evapotranspiration and other water losses on some aspen forest types in relation to water available for stream flow. Trans. Amer. Geophys. Union 34: 563-574.

Crowley, J. M. 1964. Ranches in the sky: a geography of livestock ranching in the mountain parks of Colorado. Ph.D. Thesis, Univ. of Minnesota, Minneapolis.

Curry, R. R. 1962. Geobotanical correlations in the alpine and subalpine regions of the Tenmile Range, Summit County, Colorado. M.S. Thesis, Univ. of Colo., Boulder.

Curry, Robert C. 1966. Observations of alpine mudflows in the Tenmile Range, Central Colorado. Bull. Geol. Soc. Amer. 77: 771-776.

Curtis, B. C. 1950. Structure of the north flank of the Uinta Mountains, Wyo. Geol. Assoc. Guidebook, Southwest Wyoming Geology: 93-102.

Daly, R. A. 1905. Summit levels among alpine mountains. J. Geol. 13: 105.

Daubenmire, R. F. 1938. Merriam's life zones of North America. Quart. Rev. Biol. 13: 327-332.

__________. 1941. Some ecological features of subterranean organs of alpine plants. Ecology 22: 370-379.

__________. 1942. An ecological study of the vegetation of southeastern Washington and adjacent Idaho. Ecol. Monogr. 12: 53-79.

__________. 1943. Soil temperature versus drought as a factor determining lower altitudinal limits of trees in the Rocky Mountains. Botan. Gaz. 105: 1-13.

__________. 1943. Vegetational zonation in the Rocky Mountains. The Botan. Rev. 9: 325-393.
Up to the publication date, the 175 references in this review article provide useful background information for the following vegetation zones: alpine, spruce-fir, Douglas fir, ponderosa pine, juniper-pinyon, oak mountain mahogany, and vegetation of the basal plains.

Each of the five forest climax associations occupies about 2,000 feet of vertical elevation. The upper altitudinal limits of species seem to be determined by the relative physiologic efficiency of temperature during the growing season and upper timberline is usually caused by physiologic drought resulting from the concomitance of high wind velocities and cold soil. Daubenmire suggested that the lower altitudinal limits generally are determined by drought, although lower timberline is frequently elevated above its climatic limits by bodies of fine-textured soil at low altitudes.

The author made suggestions on the significance of discontinuities of zones, lack of zonation, mountain parks, and the implications of Pacific coast species in the Rocky Mountain flora.

____________. 1952. Forest vegetation of northern Idaho and adjacent Washington and its bearing on concepts of vegetation classification, Ecol. Monogr. 22: 301-330

____________. 1954. Alpine timberlines in the Americas and their interpretation, Butler Univ. Botan. Studies 11: 119-136.

____________. 1956. Climate as a determinant of vegetation distribution in eastern Washington and northern Idaho, Ecol. Monogr. 26: 131-154.

Daubenmire, R. F., and A. W. Slipp. 1943. Plant succession on talus slopes in northern Idaho as influenced by slope exposure, Bull. Torrey Botan. Club 70: 473-480.

Davis, W. M. 1911. The Colorado Front Range, a study in physiographic presentation, Ann. Assoc. Amer. Geog. 1:21-83.

Deevey, E. S., Jr. 1949. Biogeography of the Pleistocene, Bull. Geol. Soc. Amer. 60: 1315-1416.

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Dixon, H. 1935. Ecological studies on the high plateaus of Utah, Botan. Gaz. 97: 272-320.

D'Ooge, C. L. 1955. Continentally in the western United States, Amer. Meteorol. Soc. Bull. 36: 175-177.

Dorroh, J. H. 1946. Certain hydrologic and climatic characteristics of the Southwest, Univ. of New Mexico Press, Albuquerque.

Douglass, M. M. 1954. Ecology of forest succession on a ridge in the subalpine forest of northern Colorado, M.S. Thesis, Univ. of Colorado, Boulder.

Dutton, C. E. 1882. Geology of the high plateaus of Utah, U. S. Geol. Surv. Monogr. 2: 242.

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Eardley, A. J. 1933. Strong relief before block faulting in the vicinity of the Wasatch Mountains, Utah, J. Geol. 41: 243-267.

_____________. 1934. Structure and physiography of the southern Wasatch Mountains, Utah, Bull. Geol. Soc. Amer. 50: 1277-1310.

_____________. 1939. Structures of the Wasatch - Great Basin region, Bull. Geol. Soc. Amer. 50: 1277-1310.

_____________. 1944. Geology of the north-central Wasatch Mountains, Utah, Geol. Soc. Amer. Bull. 55: 819-894.

Eardley, A. J., and E. L. Bentner. 1934. Geomorphology of Marysvale Canyon and vicinity, Utah, Proc. Utah Acad. Sci. 149-159.

Eardley, A. J., V. Gvosdetsky, and R. E. Marsell. 1957. Hydrology of Lake Bonneville and sediments and soils of its basin, Geol. Soc. Amer. Bull. 71: 1323-1344.

Elder, M. E. 1912. Roadside plants of a high mountain park in Colorado, Torreya 12: 175-180.

Ellison, L. 1943. The pocket gopher in relation to soil erosion on mountain ranges, Ecology 24: 101-114.

_____________. 1949. Establishment of vegetation on a depleted subalpine range as influenced by microenvironment, Ecol. Monogr. 19: 95-121.

_____________. 1954. Subalpine vegetation of the Wasatch Plateau, Utah, Ecol. Monogr. 24: 89-184.

The Wasatch Plateau in central Utah lies just south of the transect between 39° and 40° latitude north and 110°00' and 111°40' longitude west. This paper gives a reconstruction of the original cover on herbaceous uplands (average elevation about 10,000 feet) and a description of the gross changes that have taken place in vegetation and soil since first utilization by white settlers.

Included in this report are some excellent pairs of photographs that show changes in the appearance of the landscape during a three- or four-decade interval. A three-page description of the climate and a 76-page description of plant communities is given

for the Wasatch Plateau. A list of 205 seed plants of the plateau and a bibliography of 44 references are included.

The dominant influence on the subalpine vegetation has been the grazing of domestic livestock which began about 1870. The plateau was so overrun with sheep that it became reduced in the '80's and '90's to a "vast dust bed". As a result of removal of this heavy grazing pressure, great increases in vegetation cover have occurred in many parts of the subalpine zone during the last 40 years, but changes in vegetation on permanent quadrats during the past decade or two suggest that the upward trend has ceased. In other words, the later stages of secondary succession are slower than the initial changes from the lowest stage in secondary succession.

In addition, losses of soil by accelerated erosion are continuing. Accelerated soil erosion is not a successional process as is soil development. When the soil mantle has been stripped away, leaving only bedrock or erosion pavement, rapid improvement through secondary succession is no longer possible; the only possibility of improvement is by the slow process of soil formation and primary succession.

____________. 1960. Influence of grazing on plant succession of rangelands, The Botan. Rev. 26: 1-78.

This review article provides a summary of published information on the effects of grazing for most of western United States. The discussions include the following vegetation types of the Denver-Salt Lake City transect area: sagebrush association, saltbush-greasewood association, mountain brush and chaparral zone, montane forest zone, and subalpine forest.

There is much evidence that under heavy grazing most palatable grasses and forbs are eliminated and sagebrush increases, but Ellison does not accept the view that the widespread sagebrush association is properly grassland and that the presence of sagebrush throughout is solely the result of man's disturbance. Sagebrush is greatly retarded by fire, whereas cheatgrass is encouraged. On sagebrush-cheatgrass range there appears to be a continual tug-of-war; sagebrush persistently reinvades, but recurrent fires maintain dominance of the annuals.

Ellison, L., A. R. Croft, and R. W. Bailey. 1951. Indicators of conditions and trend on high range watersheds of the intermountain region, U. S. Dept. Agric. Forest Service Handbook 19, 66 pp.

Ellison, L., and C. M. Aldous. 1952. Influence of pocket gophers on vegetation of subalpine grassland in central Utah, Ecology 33: 177-186.

Emerson, F. W. 1932. The tension zone between the grama grass and pinyon-juniper associations in northeastern New Mexico, Ecology 13: 347-358.

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Eschman, D. F. 1955. Glaciation of the Michigan River Basin, North Park, Colorado, J. Geol. 63: 197-213.

Evans, P. A. 1926. An ecological study in Utah, Botan. Gaz. 82: 253-285.

Fautin, R. W. 1946. Biotic communities of the northern desert shrub biome of western Utah, Ecol. Monogr. 16: 251-310.

Fenneman, N. M. 1905. Geology of the Boulder district, U. S. Geol. Surv. Bull. 265.

____________. 1931. Physiography of Western United States, McGraw-Hill Book Co., New York, 534 pp.
A classic in the field that is still of considerable use today. It utilizes a regional breakdown of the United States based on physiographic provinces, which are further subdivided into section. The regional breakdown employed is still generally accepted today.

Fetherholf, J. M. 1917. Aspen as a permanent forest type, J. Forestry 15: 757-760.

Fireman, M., and H. E. Hayward. 1952. Indicator significance of some shrubs in the Escalarte Desert, Utah, Botan. Gaz. 114: 143-155.

Flint, R. F. 1957. Glacial and Pleistocene Geology, John Wiley and Sons, New York, 553 pp.

Flowers, S. 1934. Vegetation of the Great Salt Lake Region, Botan. Gaz. 95: 353-418.

Fogarty, C. F. 1951. Pediments of the Golden-Morrison area, Jefferson County, Colorado, Geol. Soc. Amer. Bull. 62: 1534 (abstract).

Forester, J. D. 1937. Structure of the Uinta Mountains, Geol. Soc. Amer. Bull. 48: 631-660.

Forsling, C. L. 1931. A study of the influence of herbaceous plant cover on surface run-off and soil erosion in relation to grazing on the Wasatch Plateau in Utah, U. S. Dept. Agric. Tech Bull. 220.

Fowells, H. A. 1965. Silvics of forest trees of the United States, U. S. Dept. Agric. Forest Service, Agric. Handbook No. 271, 762 pp.

Life histories of trees and their responses to the environment. One hundred and twenty-seven species are discussed, including the following from the transect study area: subalpine fir, white fir, Rocky Mountain juniper, Engelmann spruce, lodgepole pine, pinyon pine, ponderosa pine, aspen, Rocky Mountain Douglas fir.

An up-to-date range map is included for each species, including the range within Canada or Central America for species that extend beyond continental United States. The text description for each species is organized under the following headings: climate, soils and topography, associated trees and shrubs, flowering and fruiting, seed production and dissemination, seedling development and reproduction, growth and yield, reaction to competition, principal enemies, and races and hybrids.

Several hundred bibliographic references are listed with a separate citation list for each species and a general bibliography on the tree and its environment, dendrology, entomology and pathology, climate, soils and silvics.

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Fryxell, F. M. 1930. Glacial features of Jackson Hole, Wyoming, Augustana Library Publ. 13, 128 pp.

Garstka, W. U., L. D. Love, B. C. Goodell, and F. A. Bertle. 1958. Factors affecting snowmelt and stream flow. A report on the 1946-1953 cooperative snow investigations at the Fraser Experimental Forest, Fraser, Colorado, U. S. Dept. Interior, Bur. Reclam. and U. S. Dept. Agric., Forest Service, 189 pp.

Gates, D. T., L. A. Stoddart, and C. W. Cook. 1956. Soil as a factor influencing plant distribution on salt-deserts in Utah, Ecol. Monogr. 26: 155-175.

Gates, D. T. 1956. Ecology of plant distribution on the salt deserts of Utah, Ph.D. Thesis, Utah State Agric. College.

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Geologic Map of Colorado, 1935. U. S. Geol. Survey.

Geologic Map of Northeast and Northwest Utah, 1963. College of Mines and Mineral Industries, Univ. of Utah, Salt Lake City, Utah

Gilbert, G. K. 1890. Lake Bonneville, U. S. Geol. Surv. Monograph 1.
Gilbert notes Endlich's view (Ann. Report, U. S. Geol. and Geog. Surv. of Terr. for 1877, p. 641) that Colorado glaciation was due to moisture from Lake Bonneville. He argues that since the lake (and similar lakes) can only have returned to the air moisture precipitation from it, they cannot have increased the total moisture. During the period of overflow, the total moisture returned to the air was even less than that lost.
Rises and falls of Lake Bonneville are fairly well dated, and reasons for these fluctuations generally well documented.

____________. 1904. Systematic asymmetry of crest lines in the Sierras, J. Geol. 12: 579-588.

____________. 1928. Studies of basin and range structure, U. S. Geol. Surv. Prof. Paper 153.

Gilluly, James. 1928. Basin range faulting along the Oquirrh Range, Utah, Bull. Geol. Soc. Amer. 39: 1103-1130.

Glenn, C. L. 1961. The chinook, Weatherwise 14: 175-182.

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Gorton, K. A., 1941. Geology of the Cameron Pass area - Grand, Jackson, and Larimer Counties, Colorado, Ph.D. Thesis, Univ. of Michigan, Ann Arbor

Graham, E. H. 1935. Botanizing in the Uinta Basin, Carnegie Mag. 9: 143-147.

____________. 1937. Botanical studies in the Uinta Basin of Utah and Colorado, Ann. of Carnegie Museum 26: 432 pp.
The best single reference for information on the Uinta Basin. Vegetation zones and associations are discussed in detail, although many species names used in 1937 are no longer valid. Of most interest is Graham's treatment of vegetation zones adjacent to the basin. For the north side of the basin (south slope of Uinta Mountains) he listed the following zones and altitudinal limits: mixed desert shrub (4,500 to 5,500 feet); juniper-pinyon (5,500 to 7,000); sub-montane shrub or mid-altitude sagebrush (7,000 to 8,000); aspen (8,000 to 8,700); lodgepole pine (8,700 to 10,000); spruce-fir (10,000 to 11,000); alpine (11,000 to 13,500).
These are compared with the zones on the south side of the basin (north slope of Tavaputs Plateau, about 100 miles south of the Uinta Mountains): mixed desert shrub (4,500 to 6,000 feet); juniper-pinyon (6,000 to 7,500); sub-montane shrub, aspen and spruce-fir (7,500 to 10,000).

On the Tavaputs Plateau at 10,000 feet there are extensive areas of sagebrush, whereas at the same altitude in the Uinta Mountains there are dense forests of lodgepole pine or Engelmann spruce, despite the south slope of the Uintas and the presumably cooler north slope of the plateau. Graham explained this apparent anomaly with the suggestion that the 10,000-foot Tavaputs Plateau did not reach an altitude great enough to ensure a source of moisture throughout the growing season, as there is from the melting summer snowbanks on the slopes of the Uinta Mountains.

Zonation east and west of the Uinta Basin was not distinct. Between the Wasatch Range and the edge of the Uinta Basin the vegetation is a mixture of mid-altitude sagebrush, juniper-pinyon and upper-altitude forest types without any apparent zonation. The report contains maps, topographic cross-section diagrams and 22 photographs of good quality.

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Thirty-three species were observed to invade cushions of *Silene acaulis*; 22 were observed to invade *Arenaria obtusiloba*; 10 invaded cushions of *Paronychia pulvinata*; 21 invaded *Trifolium nanum* and seven species invaded *Trifolium dasyphyllum*.

The invasions followed a regular pattern from which a tentative competitive ladder for some of the tundra species was set up.

Hadley, R. F., and F. A. Branson. 1965. Surficial geology and microclimatic effects on vegetation, soils, and geomorphology in the Denver, Colorado, area, In: International Association for Quaternary Research Guidebook for One-day Field Conferences, Boulder Area, Colorado.

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Hail, W. J., and G. E. Lewis. 1960. Probable late Miocene age of the North Park formation in North Park area, Colorado, U. S. Geol. Surv. Prof. Paper 400-B, B259-B260.

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"Canyon winds blow every day the weather is clear, but never

when it is cloudy, unless a region of high pressure lies to the east followed by a low pressure area to the west and north. Then develops a strong east wind, often violent and destructive." These winds lengthen growing seasons tremendously in their parts. They are a comparatively shallow phenomenon. They reach a maximum velocity of 30 mph about 4 a.m. and subside quite rapidly after sunrise. They spread out in a fan-like shape over the valley floor. Their velocity is reduced as one proceeds away from the canyon mouth and to the north and south of a central line of maximum velocity.

____________. 1947-48. Characteristics of prevailing winds at Provo Municipal Airport, Proc. Utah Acad. Sci. 25: 117-126.

Hall, H. H. 1953. The impact of man on the upper valley allotment, Garfield County, Utah, M.S. Thesis, Univ. of Utah, Salt Lake City.

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Hanshaw, B. B. 1958. Structural geology of the west side of the Gore Range, Colorado, Unpubl. Master's thesis, Univ. of Colorado, 84 pp, Bolder.

Hanson, H. C. 1924. A study of the vegetation of northeastern Arizona, Univ. of Nebraska, Univ. Stud. 24: 85-175, Lincoln, Nebraska

____________. 1955. Characteristics of the Stipa comata-Bouteloua gracillis-Bouteloua curtipendula association in northern Colorado, Ecology 36: 269-280.

Floristic information on the chief grassland communities of the mountain front--grassland contact zone of northern Colorado, between Big Thompson and Little Thompson Canyons and between altitudes of 5,300 and 5,600 feet.

Most of the discussion deals with the association named in the title above because stands of this association occur over a wide range of topographic and edaphic conditions. The number of species per stand in this association varied from 23 to 49, with a total of 89 species in eight different stands of the association.

Other grassland communities were differentiated on the basis of abundance of one of the following species: big bluestem or little bluestem (characteristic of mixed prarie and tall-grass prarie further to the east on the Great Plains), Agropyron smithii (characteristic of sagebrush-bunchgrass areas to the west), Artemisia glauca, or Bromus tectorum (cheatgrass).

The chief shrub community is mountain mahogany (Cercocarpus montanus) which occurs on more rocky sites and is usually higher on the slopes than the foothill grassland communities. Other

shrub communities are characterized by Physocarpus monogynus on some north slopes, Rhus trilobata on various sites, and Rubus, Ribes and Symphoricarpos species in the valleys. Ponderosa pine is often scattered among the mountain mahogany on rock outcrops, particularly those of the Dakota formation.

Hanson, H. C., and E. Dahl. 1957. Some grassland communities in the mountain front zone in northern Colorado, Vegetatio 7: 249-269.

Hanson, H. L. 1947. Evolution of certain floristic associations in western North America, Ecol. Monogr. 17: 201-210.

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__________. 1954. Manual of the plants of Colorado, Sage Books, Denver, 666 pp.

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Hart, F. C. 1937. Precipitation and runoff in relation to altitude in the Rocky Mountain region, J. Forestry 35: 1005-1010.

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Hayden, F. B. 1874. Geology of the Elk Mountains. U. S. Geol. and Geog. Surv. of the Terr., 7th Annual Report: 53-69.

Hayward, C. L. 1945. Biotic communities of the southern Wasatch and Uinta Mountains, Utah, Great Basin Naturalist 6: 1-124.

__________. 1948. Biotic communities of the Wasatch chaparral, Utah, Ecol. Monograph 18: 473-506.

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The biotic communities at and above timberline in the Uinta Mountains were discussed by Hayward under the following headings: open water, wet meadow, dry meadow, sliderock and fell communities, and krummholz.

In this area the succession of communities that has followed the disappearance of the ice has been extremely show because of the short season of growth and the instability of steep slopes.

Furthermore, the long period of sheep grazing in the alpine tundra has had an unknown effect upon processes of community development. The gradual infilling of ponds appears to be accomplished more by physical than by biotic factors, i.e., mainly by washing in of sediment from surrounding areas rather than from accumulation of organic matter from the scanty vegetation.

An apparent floristic difference from the Colorado Rocky Mountains is that Hayward reported no fruiticose lichens (Cladonia) in the alpine communities, whereas these are present in some alpine areas of Colorado. According to Hayward's data, at least 18 inches of soil seem to be necessary for the establishment of a permanent plant community. In the Uinta Mountains, Engelmann spruce is the predominant tree at timberline, but lodgepole pine and creeping juniper are also present.

Hayward, C. L., D. E. Beck, and W. W. Tanner. 1958. Zoology of the upper Colorado River basin, Brigham Young Sci. Bull., Biol. Ser. 1, No. 3, 74 pp.

Although this is a review primarily of fauna of the upper Colorado River basin, this publication is pertinent because of the excellent landscape photographs that are included. The Manila area in northeastern Utah, and the western part of the Uinta Basin, both of which lie within the transect study area, are discussed. Descriptions of biotic communities, geology, topography, general climatic conditions and a history of exploration are given for the upper Colorado River region.

Hayward, H. E., and L. Bernstein. 1958. Plant growth relationships on salt-affected soils, Botan. Rev. 24: 584-635.

Henry, A. J. 1919. Increase of precipitation with altitude, Monthly Weather Rev. 47: 33-41.

Herman, F. R. 1958. Silvical characteristics of Rocky Mountain juniper, U. S. Dept. Agric., Rocky Mtn. Forest and Range Exp. Sta., Station Paper 29, 20 pp.

Hess, D. 1959. Ecological studies of the growth of ponderosa pine on the east slope of the Rocky Mountain Front Range in Boulder County, Colorado, Ph.D. Thesis, Univ. of Colorado, Boulder.

Hill, J.M. 1913. Notes on the northern La Sal Mountains, Grand County, Utah, U. S. Geol. Surv. Bull. 530: 99-118.

Hironaka, M. 1963. Plant environment relations of major species in sagebrush-grass vegetation of southern Idaho, Ph.D. Dissertation, Univ. of Wisconsin, Madison.

Hoff, C. C. 1957. A comparison of soil, climate, and biota of conifer and aspen communities in the central Rocky Mountains, Amer. Midland Natur. 58: 115-140.

The author demonstrates sharp changes in soil and soil moisture under aspen. The objective was to study the differences in microclimate, soil, and fauna of aspen groves and adjacent coniferous forests in Medicine Bow National Forest, Wyoming; and Roosevelt National Forest, Colorado. Comparisons were made in 15 localities for each of which precise map locations and ecological descriptions are given.

No consistent differences were found between the two types of communities with respect to relative humidity, air temperature, or light intensity during the growing season. These microclimatic factors appear to be related to topography rather than to the nature of the dominant plants. At lower elevations where ponderosa pines occur in relatively open stands there is a higher evaporation rate among the pines than among the aspen. At higher elevations where the conifers form a dense stand and the aspens are in more open stands, the evaporation rate among the aspens exceeds that in the conifers.

Holch, A. E., E. W. Hertel, W. O. Oakes and H. H. Whitwell. 1941. Root habits of certain plants of the foothills and alpine belts of Rocky Mountain National Park, Ecol. Monogr. 11: 327-345.

Holm, T. H. 1927. The vegetation of the alpine region of the Rocky Mountains in Colorado, Mem Nat. Acad. of Sci. 19: 1-45.

The author discussed the morphological characteristics of alpine plants and pointed out that creeping shrubs and caespitose herbs forming cushions are characteristic. Descriptions of a number of root systems revealed that fleshy rhizomes and bulbs are uncommon and tuberous stolons are absent.

Almost all alpine plants are perennials and reproduction is accomplished by over-wintering buds that lie close to the ground and are protected by dead foliage. Many of the roots are shallow and are thus able to absorb surface water readily. The caespitose and dense cushion habits of many of the plants serve to retard runoff from the ground surface and also discourage loss of water by transpiration.

Holmes, W. H. 1876. Report on the geology of the northwestern portion of the Elk Range, U. S. Geol. and Geog. Surv. of the Terr., 8th Annual Report: 59-71.

Holmgren, A. H. 1948. Handbook of the vascular plants of the northern Wasatch, Lithotype Process Co., San Francisco, 202 pp.

Holway, J. G. 1962. Phenology of Colorado alpine plants, Ph.D. thesis, Colorado State Univ., Fort Collins.

Holway, J. G., and R. T. Ward. 1965. Phenology of alpine plants in northern Colorado, Ecology 46: 73-83.

During the summers of 1960 and 1961, ten stations representing variations in slope, exposure, elevation, snow cover and vegetation cover were established in a 300-acre site, ranging from 10,600 to 11,200 feet in the northern part of Rocky Mountain National Park, Colorado. The purpose was to collect environmental data for correlation with stages of development of about 75 species of alpine plants from early June to late September.

Details of phenology are presented in the article and will not be annotated here. Attention is drawn to this article as another source of environmental data for the Front Range region during the growing season. The large variation in environmental conditions and vegetation within short distances in the alpine region is evident from the data of this work.

Holway, J. G., and R. T. Ward. 1963. Snow and meltwater effects in an area of Colorado alpine, Amer. Midland Naturalist 69: 189-197.

Hooker, J. D., and A. Gray. 1880. The vegetation of the Rocky Mountain region and a comparison with that of other parts of the world. U. S. Geol. Surv. Terr. 6: 1-62.

Horberg, L. 1952. Interrelations of geomorphology, glacial geology, and Pleistocene geology, J. Geology 60: 187-190.

Howard, A. D. 1941. Rocky Mountain peneplains or pediments. J. Geomorphol. 4: 138-141.

______________. 1956. Upland surfaces of the Rocky Mountains, Eighth Report, Comm. for Study and Correlation of Erosion Surfaces around the Atlantic, Internat. Geog. Union 9th General Assembly, Rio de Janiero, 1956.

Howe, E., and W. Cross. 1906. Glacial phenomena of the San Juan Mountains, Colorado, Bull. Geol. Soc. Amer. 17: 251-274.

Howell, J., Jr. 1941. Pinon and juniper woodlands of the southwest. J. Forestry 39: 542-545.

Hubbs, C. L., and R. R. Miller. 1938. The Great Basin with emphasis on glacial and postglacial times. II. The zoological evidence, Univ. Utah Bull. 38, No. 20: 18-166.

Hulbert, L. C. 1955. Ecological studies of Bromus tectorum and other annual bromegrasses, Ecol. Monogr. 25: 181-213.

Hunt, A. P. 1958. Structural and igneous geology of the La Sal Mountains, Utah, U. S. Geol. Surv. Prof. Paper 294-I: 305-364.

Hunt, C. B. 1954. Pleistocene and Recent deposits in the Denver area, Colorado, U. S. Geol. Surv. Bull. 996-C: 91-140.

Imshaug, H. A. 1957. Alpine lichens of western United States and adjacent Canada. I. The microlichens, Bryologist 60: 177-272.

International Assoc. for Quaternary Research. 1965. VII Congress, Guidebook for Field Conference E - Northern and Middle Rocky Mountains, 129 pp.

Ives, R. L. 1938. Glacial geology of the Monarch Valley, Grand County, Colorado, Geol. Soc. Amer. Bull. 49: 1045-1066.

____________. 1938. Weather phenomena of the Colorado Rockies, J. Franklin Institute 226: 691-755.

____________. 1939. River fogs of the Colorado Valley, Bull. Amer. Meteorol. Soc. 20: 415-417.

____________. 1940. Rock glaciers in the Colorado Front Range, Bull. Geol. Soc. Amer. 51: 1271-1294.

____________. 1941a. Tundra ponds, J. Geomorphol. 4: 285-296.

____________. 1941b. Forest replacement rates in the Colorado headwater area, Bull. Torrey Botan. Club 68: 407-408.

____________. 1941c. Rapid identification of the montane-subalpine zone boundary, Bull. Torrey Botan. Club 68: 195-197.

____________. 1941. Colorado Front Range crest clouds and related phenomena, Geog. Rev. 31: 23-45.

____________. 1948. Recent climatic fluctuations in the Great Basin region of the United States, Weather 3: 374-379.

____________. 1950. Frequency and physical effects of chinook winds in the Colorado high plains region, Ann. Assoc. Amer. Geogr. 60: 293-327.

____________. 1950. Glaciations in Little Cottonwood Canyon, Utah, Sci. Monthly 71: 105-117.

____________. 1952. Snow-eaters of the high plains, Weatherwise 5: 599-600.

____________. 1953. Later Pleistocene glaciation in the Silver Lake Valley, Colorado, Geog. Rev. 43: 228-252.

James, J. W. 1966a. Precipitation climatology along the east slope of the Colorado Front Range--some descriptive and physical observations, Unpubl. paper presented at the annual meeting of the Rocky Mountain Social Science Association, Fort Collins, Colorado, May 1966, 10 pp.

___________. 1966b. Route 40 Mountain Environment Transect, Colorado and Utah, Inst. for Arctic and Alpine Research, Univ. of Colo., Boulder. Final report Contract DA19-129-AMC-472(N). Project No. IK-02400-1 129.

James, S. L. 1930. Herbaceous vegetation of the two mesas near Boulder, Colorado, M.S. Thesis, Univ. of Colorado, Boulder.

Jameson, D. A. 1961. Heat and desiccation resistance of tissue of important trees and grasses of the pinyon-juniper type, Botan. Gaz. 122: 174-179.

Johnson, A. W. 1956. Ecology of subalpine forest communities in the Silver Lake Valley of the Front Range in Colorado, Ph.D. Thesis, Univ. of Colorado, Bolder, Colo.

Johnson, P. L., and W. D. Billings, 1962. The alpine vegetation of the Beartooth Plateau in relation to cryopedogenic processes and patterns, Ecol. Monogr. 32: 105-135.

Johnson, W. M. 1945. Natural revegetation of abandoned crop land in the ponderosa pine zone of the Pikes Peak region in Colorado, Ecology 26: 363-374.

___________. 1956. The effect of grazing intensity on plant composition, vigor, and growth of pine-bunchgrass ranges in central Colorado, Ecology 37: 790-798.

___________. 1962. Vegetation of high altitude ranges in Wyoming as related to use by game and sheep, Agric. Exp. Sta. Bull. 387, Univ. of Wyoming, Laramie.

Johnson, T. N. 1962. One-seed juniper invasion of northern Arizona grasslands, Ecol. Monogr. 32: 187-207.

Jones, W. D., and L. O. Quam. 1944. Glacial landforms in Rocky Mountain National Park, Colorado, J. Geol. 52: 217-234.

Jorgensen, R. D. 1958. Relation of three Artemisia species to snowfall, Colorado-Wyoming Acad. Sci. 4: 33.

Judson, Arthur. 1964. Relative importance of weather factors creating slab avalanches in Colorado, Proc. Western Snow Conf., April 1964, pp. 60-67.

____________. 1965. The weather and climate of a high mountain pass in the Colorado Rockies, U. S. Forest Service Research Paper, RM-16, 28 pp.

One of the few descriptive and physical analyses of the climate of such a high area (over 11,000 feet) in the United States. Summarizes basic data collected over a number of years at Berthoud Pass, including wind, precipitation, temperature, humidity, and snowfall. Relates weather occurrences to synoptic climatic types. Liberal use of tables, graphs, and maps.

Comparison of wind regime at Berthoud Pass with other windy sites in the world, such as Mount Washington, Mount Fuji, etc., suggests that the Niwot Ridge area and other portions of high elevations of the Front Range rank only behind Mount Fuji, Mount Washington and the Jungfraujoch in Switzerland in being the windiest known places in the world.

Kaliser, Bruce N. 1967. Giant fault straddles SL (Salt Lake City) lifeline, Quarterly Review, Utah Geological and Mineral Survey 1 (11): 6-7.

This release documents activity of the Wasatch fault.

Keiner, W. 1935. Structural analysis of alpine vegetation on Long's Peak, Colorado, J. Colorado-Wyoming Acad. Sci. 2: 50-51.

____________. 1939. Sociological studies of the alpine vegetation on Long's Peak, Colorado, Ph.D. Thesis, Univ. of Nebraska, Lincoln.

Kershaw, K. A. 1963. Pattern in vegetation and its causality, Ecology 44: 377-388.

Morphological pattern may be simply a result of the morphology or reproductive methods of a particular species. Vegetative reproduction by layering of the lower branches in subalpine conifers could result in a vegetation pattern of the kind suggested in this category.

Environmental pattern is much better known because the effects of major discontinuities of environmental factors upon vegetation are often well marked. In this study the term sociological pattern is intended to cover a range of pattern units, the products of several interrelated causal factors. This category includes patterns that are partly a result of intrinsic properties of the plants themselves and partly a reflection of microenvironment. Patterns resulting from various interspecies relationships, such as mutualism or competition, would be classed by Kershaw as sociological.

Klemmedson, J. O., and J. G. Smith. 1964. Cheatgrass (Bromus tectorum L.), Botan. Rev. 30: 226-262.

Knapp, Rudiger. 1965. Die vegetation von Nord und Mittelamerika und der Hawaii Inseln, Gustav Fischer Verlag, Stuttgart.

Korstian, C. F. 1921. Effect of a late spring frost upon forest vegetation in the Wasatch Mountains of Utah, Ecology 2: 47-52.

Kuchler, A. W. 1964. Manual to accompany the map, Potential natural vegetation of the conterminous United States, Amer. Geog. Soc., Spec. Publ. No. 36. 39 pp. and 110 plates.

In this manual there is a precise definition of the objects to be mapped. "Potential natural vegetation," as distinguished from "real vegetation," which includes wheat fields, etc., is defined as the vegetation that would exist under the present climate if man were removed from the scene and if the resulting plant succession were telescoped into a single moment. The latter point eliminates the possible effects of future climatic fluctuations. Potential natural vegetation is an important object of research because it reveals the biological potential of each biotype; its disadvantage is that map users may be more interested in what is on the ground at the present time (the "real vegetation").

The vegetation types on the map are all characterized by life-forms and taxa (e.g., Physiognomy: tall, needleleaf, evergreen forest. Dominants: grand fir (Abies grandis) and Douglas fir (Pseudotsuga menziesii). The manual should be considered a part of the map because it contains a legend for each vegetation type that could not be included on the map. Particularly important are the notations on regions of occurrence and the lists of dominant and other component species for each type. Species are listed for each vegetation type in alphabetical order rather than in their order of prominence.

The 110 photographic plates are excellent and were chosen to portray, wherever possible, mature stands of each vegetation type. Ten of the illustrated vegetation types occur within the transect area between Denver and Salt Lake City. A valuable bibliography of 318 entries includes references to vegetation studies in every phytogeographic region of the conterminous United States.

Kuchler, A. W., and J. McCormick. 1965. Vegetation maps of North America, Vol. 1. International bibliography of vegetation maps, Univ. of Kansas Publ., Library Ser. No. 21, 453 pp.

This volume lists 17 published vegetation maps of conterminous United States, 46 of western North America, 41 of Colorado, and 17 of Utah. Of the 104 maps of western United States, Colorado and Utah, approximately 30 contain distributional information pertinent to the transect study area between Denver and Salt Lake City.

Kuchler, A. W. 1964. Potential natural vegetation of the conterminous United States, Amer. Geog. Soc. Publ. 36, 38 pp.

Laird, H. B. 1951. Forecasting precipitation on the west slope of Colorado, Monthly Weather Rev. 79: 1-7.

Langenheim, J. H. 1949. Physiography and plant ecology on a subalpine earthflow, Gunnison County, Colorado, M.S. Thesis, Univ. of Minnesota, Minneapolis.

_____________. 1953. The plant communities and their environment in the Crested Butte area, Gunnison County, Colorado, Ph.D. thesis, Univ. of Minnesota, Minneapolis.

_____________. 1955. Flora of the Crested Butte quadrangle, Colorado, Madrono 13: 64-80.

_____________. 1956. Plant succession on a subalpine earthflow in Colorado, Ecology 37: 301-317.

The author described community relations on the Gothic earthflow which occurred in 1923 in East River valley in the Elk Mountains of Colorado. Of particular interest is the discussion of the ecological role of aspen in this area. Aspen communities occur from 8,500 to 11,200 feet, but are best developed at altitudes between 9,500 and 10,500 feet. Aspen occurs as scattered groves in the fescue meadows, but generally forms a continuous belt below the Englemann spruce-subalpine fir zone. Except in areas where it has replaced burned forest, there is little evidence of aspen being replaced by spruce or fir, as is generally considered the case.

_____________. 1962. Vegetation and environmental patterns in the Crested Butte area, Gunnison County, Colorado, Ecol. Monogr. 32: 249-285.

Environmental patterns of the Crested Butte area are discussed under the following headings: parent materials, topography, frost phenomena, climatic conditions, slope exposure and biotic conditions. Composition and structure and coincidence with environmental patterns are described for the following community types: sagebrush, aspen, spruce-fir, upland herb, alpine, fescue meadow, Douglas fir, and hydric communities.

The most valuable part of the report for the Denver-Salt Lake City transect study is the four-page comparison of the Crested Butte community types with other areas in the Rocky Mountains and Great Basin. Some pertinent conclusions of Langenheim's study are: 1) As a result of ecotypic differentiation and asexual reproduction, aspen appears to occupy a wide range of habitats, and some aspen replacing burned spruce-fir forest is successional, whereas most of the aspen community type appears relatively stable.

2) The vegetation patterns of the Crested Butte area appear more closely allied with those of southwestern Colorado and mountainous areas in the Great Basin than to those of other areas in the Colorado Rockies, particularly on the east slope.

This relationship is supported by the following occurrences in the Crested Butte area: 1) a sagebrush community type as high as 9,500 feet similar to the upper sagebrush-grass zone in the Great Basin, 2) a fescue grassland known previously from the Abajo Mountains, Utah, 3) an altitudinally defined belt of relatively stable type of aspen similar to that reported in western Colorado and eastern Utah, 4) an upland herb zone previously known from the Wasatch Plateau, 5) Great Basin species in the alpine zone.

For each vegetation type, cover values are given for every species that occurs in 30 percent or more of the stands. The bibliography contains 156 entries.

Langenheim, R. L. 1952. Pennsylvanian and Permian stratigraphy in the Crested Butte quadrangle, Colorado, Amer. Assoc. Petrol. Geol. Bull. 36: 543-574.

______________. 1954. Maroon Formation and associated rocks in the Crystal River valley, Colorado, Amer. Assoc. Petrol. Geol. Bull. 38: 1748-1779.

Larsen, J. A. 1930. Forest types of the northern Rocky Mountains and their climatic control, Ecology 11: 631-672.

Laycock, W. A. 1958. The initial pattern of revegetation of pocket gopher mounds, Ecology 39: 346-351.

LeBarron, R. K., and G. M. Jemison. 1953. Ecology and silviculture of the Engelmann spruce-alpine fir type, J. Forestry 51: 349-355.

Lee, W. T. 1922. Peneplains of the Front Range and Rocky Mountain National Park, Colorado, U. S. Geol. Surv. Bull 730a.

Argues for 3-cycle development of the Front Range, producing the Flattop and Rocky Mountain peneplains and presently eroding (canyon) surfaces. Recognized role of snow drift by westerly winds in forming cirques; flattop peneplains are the source area.

Leonard, H. A. 1916. Aspen groves of Boulder Park at Tolland, Colorado, M.A. Thesis, Univ. of Colorado, Boulder.

Little, H. P. 1925. Erosional cycles of the Front Range and their correlation, Bull. Geol. Soc. Amer. 36: 495-512.

Livingston, B. E., and F. Shreve. 1921. The distributions of vegetation in the United States as related to climatic conditions, Carnegie Inst., Washington, D.C., publ. 284.

Livingston, R. B. 1949. An ecological study of the Black Forest, Colorado, Ecol. Monogr. 19: 123-144.

Longwell, C. R. 1946. How old is the Colorado River? Amer. J. Sci. 244: 817-835.

Love, L. D., and B. C. Goodell. 1960. Watershed research on the Fraser Experiment Forest, J. Forestry 58: 272-275.

Loveless, C. M. 1963. Ecological characteristics of a selected mule deer winter range, Ph.D. Dissertation, Colorado State Univ., Fort Collins, Colorado.

Lovering, T. S., and E. N. Goddard. 1950. Geology and ore deposits of the Front Range, Colorado, U. S. Geol. Surv. Prof. Paper 223, 319 pp.

Lovering, T. S., and O. Tweto. 1953. Geology and ore deposits of the Boulder County Tungsten District, Colorado, Geol. Surv. Prof. Paper 245, 198 pp.

Lull, H. W., and L. Ellison. 1950. Precipitation in relation to altitude in central Utah, Ecology 31: 479-484.

The four stations at which observations were made were in the following vegetal zones: valley sagebrush, mountain brush, aspen-fir, and subalpine. Precipitation for the period 1934-48 was slightly above average in central Utah. Precipitation increases at 5.17" per 1,000 feet.

Station	Elevation (feet)	Annual Precip. (inches)	Stand. Error (inches)	Coef. of Variation
"Ephraim" valley site	5,443	10.88	0.76	27.0%
"Oaks" Mt. Bruser	7,655	20.10	1.08	20.8%
"HQ" aspen-fir	8,850	29.53	1.48	19.4%
"Meadows" subalpine	9,860	32.21	1.42	17.0%

Seasonal distribution: February, March, and April are decidedly above average; May and June a little below; July, August, and September much less; October, November, December and January are average. Two marked seasons: late winter maximum and late summer minimum. Discusses sources of precipitation after Dorrah 1946. The zone of maximum precipitation is non-existent and he questions Price and Evans (1937) on this point.

Luti, R. 1953. Ecological features of the vegetation of a ridge in the montane forest of Boulder County, Colorado, M.A. Thesis, Univ. of Colorado, Boulder.

McClain, E. P. 1952. Synoptic investigation of a typical chinook situation in Montana, Bull. Amer. Meteor. Soc. 33: 87-94.

Foehn need not imply windward precipitation; it may be simple descending air. Subsidence aloft and removal of leeward cold air precedes windward precipitation (A. von Flicker). Problem of cold air removal. No clear explanation; description of circumstances. Mid-troposphere air is ascending above the descending foehn. Frictional and inertial causes seem implied, though not stated. Bibliography.

______________. 1958. Some effects of the Western Cordillera of North America on cyclonic activity in the United States and southern Canada, Florida State Univ. Dept. of Meteorology Technical Report No. 12.

Author investigated behaviour of cyclonic storm systems over and in the vicinity of the Western Cordillera of North America. Two general hypotheses evolved: 1) Lee cyclogenesis--a low-level leeside trough is established and positive vorticity tendencies are generated in this region by the nature of the orographic vertical velocities; 2) windward retardation and cyclodysis--mature cyclones approaching the windward slopes decelerate, recurve northward and weaken due to the combined action of low-level orographic vertical velocities, friction, and the relatively unimpeded progression of the high-level portion of the system.

The predominant reason for the high frequency of anticyclogenesis and of anticyclones in the general Great Basin is probably the trapping and stagnation of maritime polar air in the numerous valleys and sub-basins of this area. However, when a cold front or cold front occlusion passes eastward across the northwest United States, the closed cell of high pressure behind the front seldom follows the front inland. Instead, it is generally observed that a separate lobe breaks off and/or develops in the basin area.

MacDonald, N., and H. Harrison. 1960. Some observations of the mountain wave in eastern Colorado, Bull. Amer. Meteorol. Soc. 41: 627-632.

An analysis of the occurrence of mountain wave clouds over the east slopes of the Colorado Front Range to determine the synoptic conditions which are most suitable. West-northwest winds aloft are most conducive to the development of lee waves and crest clouds, etc., in the area west of Boulder, probably because the Continental Divide is oriented slightly east of north and west of south in this area, thus presents a right angle front to west-northwest winds, but not to west winds.

McHenry, D. E. 1929. The vegetation of Gregory Canyon, Colorado, M.A. Thesis, Univ. of Colo., Boulder.

McIntosh, A. C. 1923. Vegetation at different elevations in Boulder Canyon, M.A. Thesis, Univ. of Colo., Boulder.

McKnight, E. T. 1940. Geology of area between Green and Colorado Rivers, Grand and San Juan Counties, Utah, U. S. Geol. Surv. Bull. 908, p. 147.

MacQuoun, W. C., Jr. 1945. Structure of the White River Plateau near Glenwood Springs, Colorado, Geol. Soc. Amer. Bull. 56: 877-892.

McKell, C. M. 1950. A study of plant succession in the oak brush (Quercus gambelii) zone after fire, M.S. Thesis, Univ. of Utah, Salt Lake City.

Mackin, J. H. 1937. Erosional History of the Big Horn Basin, Wyoming, Bull. Geol. Soc. Amer. 48: 838-859.

____________. 1938. (Review of W. H. Bradley 1936), J. Geomorph. 1: 70-72.

____________. 1947. Altitude and local relief of the Big Horn area during the Cenozoic, Wyo. Geol. Assoc. Field Conference in the Big Horn Basin, Guidebook: 103-120.

Madole, R. F. 1960. Glacial geology of upper St. Vrain valley, Boulder County, Colorado, M.S. Thesis, Ohio State Univ., 109 pp.

Magistad, O. C. 1945. Plant growth relations on saline and alkali soils, Botan. Rev. 11: 181-230.

Malde, H. E. 1955. Surficial geology of the Louisville quadrangle, U. S. Geol. Surv. Bull. 996-E: 217-257.

Marr, J. W. 1958. Lee slope stands in the upper part of the forest-tundra ecotone on Niwot Ridge, Boulder County, Colorado, J. Colorado-Wyoming Acad. Sci. 4: 41.

____________. 1959. Forms of tree islands in alpine tundra, J. Colorado-Wyoming Acad. Sci. 4: 34.

____________. 1961. Ecosystems of the east slope of the Front Range in Colorado, Univ. of Colo. Stud., Ser. in Biol. No. 8, 134 pp.
This report provides for the east slope of the Colorado Front Range more comprehensive ecological information than has been published for any other portion of the transect study area. It describes 30 widespread stand-type from four climax regions: the

lower montane (6,600 to 7,700 feet); the upper montane (8,000 to 9,000 feet); the subalpine (9,300 to 11,000 feet); and the alpine (11,400 feet to mountain tops).

Included are 10 excellent photographs, a 6-page discussion of regional features of the Front Range, 16 pages of summarized environmental data (October 1952 - October 1953) for four stations from each of four climax regions and a list of all plants (358 species, excluding lichens and bryophytes) encountered in the study.

____________. 1964. The vegetation of the Boulder area, In: Natural history of the Boulder area, Univ. of Colo. Museum Leaflet 13: 34-42.

____________. 1965. Forest ecology of the Front Range, In: International Assoc. for Quaternary Research Guidebook for one-day conferences, Boulder area, Colorado: 16-20.

____________. 1967-68. Data on mountain environments, Front Range, Colorado,

I. Sixteen sites 1952-1953.
II. Four climax regions 1953-1958
III. Four climax regions 1959-1964.

Contributions 51 to 53, Inst. of Arct. and Alp. Research, Univ. of Colo., Boulder.

Marsell, R. E. 1931. Salient geological features of the Traverse Mountains, Utah, Proc. Utah Acad. Sci. 8: 106-110.

____________. 1964. Geomorphology of the Uinta Basin--a brief sketch, Intern. Assoc. Petrol. Geol. 13th Annual Field Conf. Guidebook: 29-37. Divides the Uinta Basin into six subdivisions based on geological and/or physiographic features.

1. Northeastern District
2. Central Badlands District
3. Tavaputs Plateau
4. Upper Duchesne River Plateau
5. Green River Valley
6. Douglas Creek area.

Marston, R. B. 1952. Ground cover requirements for summer storm runoff control on aspen sites in northern Utah, J. Forestry 50: 303-307.

Martinelli, M., Jr. 1965. Accumulation of snow in alpine areas of central Colorado, and means of influencing it, J. Glac. 5: 625-636.

________. 1965. An estimate of summer runoff from (Colorado) alpine snow fields, J. Soil and Water Conserv. 20: 24-26.

Merkle, J. 1952. An analysis of a pinyon-juniper community at Grand Canyon, Arizona, Ecology 33: 375-384.

________. 1954. An analysis of the spruce-fir community on the Kaibab Plateau, Arizona, Ecology 35: 316-322.

Merriam, C. H. 1898. Life zones and crop zones of the United States, U. S. Dept. Agric., Div. Biol. Surv. Bull. 10, 79 pp.

Miller, P. 1964. Factors influencing the vegetation patterns on the White River Plateau in northwestern Colorado, Ph.D. Thesis, Univ. of Colo., Boulder, 212 pp.

Miller, R. L., and G. A. Choate. 1964. The forest resource of Colorado, U. S. Forest Service Resource Bull. INT-3, 54 pp.

The timber inventory data in this report are from the first comprehensive survey of Colorado's forest resources, completed in 1959. About 1/3 of Colorado is forest land (22.6 million acres), and spruce-fir is the most widespread forest type, occupying 28% of the commercial forest area.

The report includes: a map of commercial and noncommercial forests in relation to Colorado landforms, adapted from a map by Erwin Raisz; a diagram of the principal forest types of Colorado as related to altitude, for both eastern and western slopes, sixteen panoramic and close-up photographs of various landscapes and forest types; individual distribution maps of Engelmann spruce-subalpine fir forests, forests on table lands, lodgepole pine forests, ponderosa pine forests, Douglas fir forests. A larger fold-out map includes the above forest types plus pinyon-juniper, chaparral, and nonforested areas.

The text of this report deals mainly with inventory data, ownership information, and management suggestions for each forest type, rather than with ecological descriptions. For the entire state of Colorado, the relative coverage by various commercial forest types is as follows, in millions of acres: spruce-fir (3.4); ponderosa pine (2.3); lodgepole pine (2.1); Douglas fir (1.5); aspen (2.8); limber and bristlecone pine (0.1); cottonwood (0.1).

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forest are usually spruce. Spruce trees with a diameter of 40 inches at breast height are common in the Medicine Bow Mountains.

The spruce-fir forest is a floristically uniform and ecologically simple association. No significant phytosociological differences were found to be correlated with site, exposure or altitude. A similar unity and simplicity of subalpine conifer forests has been demonstrated for the Sierra Nevada and Appalachian mountain systems. Thus, the information given in the paper by Oosting and Reed applies without great modification to the spruce-fir forests within the transect area in Colorado and Utah.

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slope, soil acidity, hygroscopic soil moisture, range desirability indices, and indices of similarity to the two most closely related communities.

Among the detailed ecological and ordinational descriptions, the following interesting phytogeographical points were made:

1) Although there are a few scattered trees of ponderosa pine, this species contributes little to the forest composition of these mountains. This is very unusual, since ponderosa pine forests occur in the Uinta Mountains to the east, in Idaho to the north, and in various mountain ranges south and west of the Wasatch Range in Utah.

2) White fir and Gambel oak are restricted to the southern half of the range. White fir reaches its northern limit around Ogden Canyon and Gambel oak in the vicinity of Mount Willard near Brigham City, Utah.

3) Lodgepole pine is restricted to the portion of the range from Cache County, Utah, northward.

4) Aspen forests have the largest areal extent of any community in the Wasatch and there is little doubt that aspen occupies some sites on a self-perpetuating basis.

5) A unique feature of the vegetation on north exposures or ravine bottoms (between 4,600 and 7,000 feet) is the mixture of maple (Acer grandidentatum) and Gambel oak. These stands have the appearance of a miniature deciduous forest of eastern North America and the maple and oak seem to play ecological roles here similar to those held in eastern forests by these genera.

6) There is no juniper-pinyon zone in the Wasatch Mountains. Pinyon pine is present only in the Mount Nebo area. Juniper is more widespread but originally occupied only dry rocky ridges between 5,200 and 7,400 feet. Present juniper stands in the Wasatch occur on areas that have been continuously overgrazed. The junipers are usually fairly uniform in age in any one stand with many stands in the 40- to 60-year range. Another indicator of overgrazing, cheatgrass (Bromus tectorum), has a high frequency (65%) in the juniper communities.

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Eleven pages are devoted to a description of geology, landforms, drainage, climate. vegetation, wildlife, and land use. Twenty-three different mapping units, including both soil series and certain parent materials, are described from the point of view of genesis and morphology. The final written section of the report considers soil utilization and management and provides a suitability classification of soils based on range, forest, and water uses.

The soil map and accompanying report are sources of information on acreages of trees and grassland in each watershed, and also the acreages of rock out-crop, rockslides and eroded soils. The survey also provides acreages, slope, and location of these land types in the alpine zone where snow accumulates and those land types where erosion by wind, water or gravity is prevalent.

Twenty-six photographs provide views of various alpine landscapes and alpine soil profiles. One of the most valuable parts of this report for users in the field is the series of 14 aerial photograph mosaics at a scale of 1:31,680, on which the alpine soil types are mapped together with certain topographic and cultural features.

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Deposits of two younger late Pleistocene glaciations occur on the floors of the canyons. The older of these deposits

compromises two sets of large mature moraines correlated with the Bull Lake glaciation of Wyoming. The moraines represent two distinct advances of the ice that reached average altitudes of 4,980 and 5,000 feet at the mouths of the canyons and were separated by a withdrawal of the ice to the upper parts of the canyons and possibly to the cirques.

Deposits of the younger late Pleistocene glaciation, correlated with the Pinedale glaciation of Wyoming, comprise three sets of moraines. These are located in the middle and upper parts of the canyon at average altitudes of 6,570 and 7,220 and 9,190 feet. They mark one maximum and two minor readvances of the ice, separated by relatively short recessions.

During the succeeding interglacial interval, the altithermal interval of Antevs, the glaciers disappeared entirely and a submature soil formed. Later, in Recent time, two sets of small moraines or rock glaciers formed in the cirques. These are correlated with the Temple Lake and historic stades of Neoglaciation (Little Ice Age) in the Wind River Mountains of Wyoming. The lower till of the Bull Lake glaciation intertongues with and is overlain by the deposits of the first rise of Lake Bonneville, which attained an altitude of about 5,100 feet. The upper till intertongues with and is overlain by deposits of the second rise of the lake, which formed the Bonneville shoreline (elevation 5,135 feet). The maximum of both rises seem to have shortly followed the glacial maxima.

Deposits formed during the fall of the lake, during its stillstand at the Provo shoreline (4,800 feet) and during its subsequent desiccation are correlated with those of the recession and disappearance of the Bull Lake glaciers.

The lower, middle and upper tills of the Pinedale glaciation are inferred to correlate with the deposits of three fluctuations of a post-Provo rise of the lake. These attained upper limits of 4,770, 4,470, and 4,410 feet. Deglaciations accompanied the final fall and desiccation of the lake.

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2. Soil temperature decreases with increasing altitude.
3. Soil temperature is higher on south slopes than north.
4. Vegetation differences are due to insolation and soil temperature.
5. Maximum temperatures vary more than minima.
6. North/south slope differences are greater at altitude.
7. Night temperatures are as low at low altitudes as at high.
8. In hot weather north and south exposures become more differentiated at altitude, less differentiated at low levels.
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Fourteen conifers and 20 broad-leaved trees are listed and there is a brief discussion of the early uses of each. Some of the

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The introduction to this flora contains a general discussion of phytogeography of Utah and Nevada, a chapter on plant communities in this region, and a chapter on the foothill-montane-alpine flora and its environment. The frontispiece contains a rather generalized map of the belts of vegetation in these two states.

Of more interest to the present transect study are the specific comparisons that are made with photographs between landscapes in southwestern United States and in the Iberian Peninsula and North Africa. Phytogeographic comparisons of these two regions of the world are also presented. For example, many members of the family Chenopodiaceae are indicators of an arid climate and a saline soil. This family is represented by many species in both the Great Basin and in Spain. The foothill vegetation of Utah and Nevada is characterized by species of juniper of the Sabina group. In the Old World, four species of that group of Juniperus are characteristic of similar areas. The higher slopes in both regions are crowned with extensive forests of spruce and fir.

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rock terraces", all at timberline. None extend below 11,000 feet; upper margins reach 12,000 feet in some cases (map, not text, is elevation source). Vanderwilt considers the high benches evidence of a prior stage of glaciation, later glaciation having trenched deeper.

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A very complete summary of the fluctuations of the small Arapahoe Glacier (largest in the southern Rockies) over the past 60 years. Also, a detailed analysis of the structure and budget of this "drift" glacier. Notes that, although the glacier is much smaller than it was around the turn of the century, it has grown in recent years.

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The southern Rocky Mountains are considered to be those ranges to the south of the Wyoming deserts, west of the Great Plains, north of Santa Fe, New Mexico, and westward to and including the Wasatch, Uinta, La Sal, and Abajo Mountains in Utah and the San Francisco Peaks of Arizona. This region represents a logical floristic unit for consideration by plant geographers because it is effectly isolated from floristic traffic on all sides by plains, deserts or lower mountain ranges.

This report gives an historical review of vegetation studies in the southern Rocky Mountains, a brief discussion of late Cenozoic fossil plants from Colorado, and a detailed discourse on the origin of the modern flora.

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The most favorable weather map situation for strong winds over and near the Wasatch Mountains is a large high northeast and a vigorous low in Utah and Arizona.

Cold air tends to spill down the canyons themselves and remain there. Destructive winds are more widespread over the

valleys to the west in the spring because the more unstable air allows the surface and air aloft to mix more readily, bringing the strong easterlies down to the surface.

Williams, Philip, Jr., and Eugene L. Peck. 1962. Terrain influences on precipitation in the intermountain west as related to synoptic situations, J. Applied Meteorol. 1: 343-347.

Precipitation in the Wasatch Front area of northwest Utah was analyzed with regard to different storm types. It was found that precipitation associated with "cold lows" aloft was relatively greater at valley than at mountain stations when compared with cold or warm frontal precipitation. Also, the precipitation profile across the mountain range differed with "cold low" and "non-cold low" type storms.

The ratio of the Silver Lake Brighton (8,700 feet) to Salt Lake City (4,220 feet) precipitation varies from 3.75 - 1 for the non-cold low storms to 2.45 - 1 for the "cold low" storms. In "cold low" type storms, precipitation may result with relatively little dependence on orographic lifting, as compared to other storm types, and the precipitation ratios, mountain to valley stations, is relatively small.

Classification of the "non-cold low" storms were: 1) over-running warm air, 2) precipitation following a cold front, 3) miscellaneous or air mass showers: pre-warm frontal or post-warm frontal precipitation in moist air currents. Ratios were 5.5 - 1 for warm front, 7 - 1 for cold front, and 9 - 1 for miscellaneous.

The precipitation ratio in the lee of the mountain range (Heber) is less than unity for cold low storms, but greater for others.

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Wilson, J. W. 1959. Notes on wind and its effects in arctic-alpine vegetation, J. Ecology 47: 415-427.

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By pigmy conifer is meant the juniper-pinyon forest which extends from southern Idaho and southwestern Wyoming southward into Mexico. This forest type covers about 20% of Utah and is scattered over the entire state. The pigmy conifer forest lies mainly within the precipitation belt of 10 to 15 inches and most discontinuities in this forest (usually with alternating sagebrush) are associated with differences in moisture-supplying conditions of adjacent soil-types.

There is an implication that sagebrush can persist in areas where there is less available water than that required for the pigmy conifers, but evidence on this point is not conclusive. For example, Woodbury mentioned that where sagebrush and juniper come together on intermediate soils juniper seedlings become established beneath the sagebrush and eventually replace the sagebrush.

Woodin, H. E. 1953. The pinyon-juniper association in the eastern foothills of the Rockies, Ph.D. Thesis, Purdue Univ., Lafayette, Indiana.

Woodin, H. E., and A. A. Lindsey. 1954. Juniper-pinyon east of the Continental Divide, as analyzed by the line-strip method. Ecology 35: 473-489.

The main area studied extends from the Davis Mountains in Texas to the Colorado-Wyoming boundary and is bounded on the west by the Continental Divide.

There is a discussion of the climate in the east-slope juniper-pinyon woodland, although most of it pertains to Texas, New Mexico, and the southern half of Colorado. The article also contains a good description of tree distribution as related to climatic conditions.

An interesting graph shows the altitudinal changes in the relative amounts of component tree species in this forest type. Pinyon pine (Pinus edulis) increases in cover value from about 20% at 6,500 feet to 70% at 7,700 feet and the genus Juniperus decreases from about 65% at 6,500 feet to 25% at 7,700 feet. Not until an altitude of 7,200 feet or its equivalent is reached is there an equal cover contribution by pines and junipers.

Of particular interest is the small stand of pinyon pine that occurs 16 miles north of Fort Collins, east of Route 287, at an altitude of about 6,000 feet. Ordinarily, Colorado Springs is given as the northern limit of this species.

Woolley, R. R. 1946. Cloudburst floods in Utah, 1850-1938. U. S. Geol. Surv. Water Supply Paper No. 994.

This report contains several maps of possible military application. The distribution of cloudburst floods in Utah is shown in relation to 13 different land classification units at a map scale of 1:750,000. Three additional maps at a scale of 1:34,200 provide the following details for specific catchment basins or canyons: species composition (oak, maple, aspen, birch, mountain brush, sagebrush, or grass); percentage cover by rock slides and rock outcrops, steepness of slope, and soil depth.

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13. ABSTRACT

The crests and slopes of mountain ranges, and basin floors intervening between them, along U.S. Route 40 between Salt Lake City and the Denver-Boulder area, are described here by means of text, 70 photographs, and 8 maps with climatic and topographic data. The bibliography contains 570 entries. All of the highly varied terrain of the study transect is found to be accessible to military forces, and it could all be involved to one degree or another in any warfare which might occur there. Actual warfare in the study transect is not envisioned, but combat in analogous Eurasian terrain is a possibility which cannot be discounted for various reasons.

Particular features of the terrain are examined and discussed here with respect to the nature and extent of their characteristic environmental rigors, their trafficability, the prevalence of defile problems, and the potential usefulness of aerial mobility. It is concluded that small irregular forces are at great advantage in high mountain terrain as compared with large regular formations, and that the military advantages of advanced technology have until now been minimal there, but that aerial mobility, which bypasses defiles, will alter that situation in the near future.

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